RFID BASED 3D BURIED ASSETS LOCATION SYSTEM

SUBMITTED: June, 2007
PUBLISHED: April 2008
EDITORS: B. Akinci and C. Anumba.

Krystyna Dziadak, Research Student
Glasgow Caledonian University, Scotland
email: kdz1@gcal.ac.uk

James Sommerville, Professor of Construction Management
Glasgow Caledonian University, Scotland
email: jso@gcal.ac.uk

Bimal Kumar, Professor of IT in Design and Construction
Glasgow Caledonian University, Scotland
email: bku@gcal.ac.uk

SUMMARY: *This paper presents research aimed at developing a three dimensional (3D) buried assets locating system based on Radio Frequency Identification (RFID) technology. RFID is employed to improve the locating of underground infrastructure. Problems facing the utility companies are highlighted and discussed. Within the paper, differences between system performance in real conditions and ideal conditions will be examined. Other factors, which may affect the overall performance characteristics of the system, such as RF tag type, antennae, and soil conditions will also be analysed and discussed.*

KEYWORDS: *buried asset, location system, data management, RFID, utility.*

1. INTRODUCTION

Currently, there is confusion and misunderstanding within utility companies surrounding the location of buried assets. This situation is caused by the lack of accurate data and management systems for buried assets. According the 2006 Report “A review of current practice and future requirements” published by the National Underground Assets Group (NUAG), such systems should facilitate the collection, storage and updating of utility location information in a format that is accessible at any time to interested parties. The reality is that the records currently available amongst utility companies range from well coordinated to non-existent (Booth, 2005).

Some live services are not present on any utility plans. Where location records exist they are often incorrect, suggesting inaccurately the position of buried utilities. These records are usually only sufficient to locate the utility line in two dimensions (2D), commonly in the form of a line on a map. The third dimension, depth, is critically important for the construction of accurate three-dimensional (3D) plans (NETTWORK, 2002).

It is essential to know the accurate location of buried objects before beginning the excavation process. The consequences of not accurately positioning buried asset, frequently forces utility contractors to dig trial holes with very great caution which results in delays in road works, affecting the public (Cumberbatch, 2005).

Existing technologies to locate buried assets include non-destructive as well as destructive methods. Non-destructive technologies include ground probing radar (GPR), acoustic devices and induced current. Destructive methods involve guiding a boring machine which threads its way through underground services and pulls a pipe or cable behind it (Cumberbatch, 2005).

Even though existing methods are useful in varying degrees, none provide satisfactory accuracy and system efficiency; the methods are expensive and time consuming, and the data is not compiled in a common format. Additionally, none of the methods are able to provide accurate and comprehensive data on the location of non-metallic buried pipes (ITRC, 2003). Plastic pipes are the most difficult to detect because they do not emit energy and therefore cannot be located using current methods. Services buried in concrete are causing similar difficulties as plastic pipes and require more thorough investigation.

As a result of the UK's New Roads and Street Works Act (1991) there is a serious need to gather and exchange information between utility companies and highways to facilitate street works co-operation. To help achieve it initiatives were taken by the Highway Authority and Utility Committee (HAUC) who issued a "Code of Practice for recording of underground apparatus in streets" and, by the National Joint Utility Group (NJUG) who published "Guidelines on the positioning and colour coding utility's apparatus" (2003) and "Recommendations for the exchange of records of apparatus between utility companies" (2003), (UK WIR, 2006). The HAUC also emphasise that accurate records of plastic pipes should be kept and a method to enable the tracing of this type of pipe should be found.

Despite these attempts to create a common format, data is still recorded in various referencing standards, resulting in inefficiency and works delay. As none of the standards have been legislated as mandatory, utility companies continue to work to their own internal standards. This situation has amounted to an inaccessible and inefficient buried asset location data management system.

2. APPROACH BASED ON RFID TECHNOLOGY

2.1 RFID Technology

Radio Frequency Identification (RFID) technology has been evolving for over a decade and has recently become one of the leading asset management technologies.

RFID is a wireless automatic identification (Auto-ID) technology that allows for contactless reading and is effective in manufacturing and other hostile environments where bar code labels could not survive. The technology includes devices called tags (the transponders), antennae and readers (the transceiver). Passive tags rely on an electromagnetic field to supply the power necessary to exchange data between the transponder and the reader, whereas active tags use a battery to exchange the data with the reader.

The technology is based on a range of radio frequencies (RF) such as, 125 kHz - low frequency (LF), 13.56MHz - high frequency (HF), 868-915MHz - ultra high frequency UHF and 2.45GHz - microwaves. Depending on the application and environment, different frequencies are used. For example, operating on a lower frequency means less absorption by moisture, better omni-directional capability, less impact from the presence of metal, but a shorter signal range and a slower reading. Higher frequency means a longer reading range, higher speed, but more interference from metal. The efficiency of the energy transferred from the reader to the tag and the data rate are also affected by the frequency (MICROLISE, 2003).

Today, RFID is visible in a wide range of markets including livestock identification and automated vehicle identification (AVI) systems because of its ability to track moving objects (MedicAlert Technology, 2005). The technology has become a primary player in automated data collection, identification, and analysis systems for organisations such as Wal-Mart.

High accuracy, high reading speed, resistance to harsh environments (mud, rain or frog), are just a few of the benefits that characterise RFID-based systems.

Selecting the most appropriate RFID system for a particular application without understanding this technology can be difficult, time costing and confusing. All RFID systems work on the same basis and involve the same components, but differ when it comes to frequency bands, system range, system operation or coupling (Finkenzeller, 2005). Each of these features has a significant impact on the efficiency and performance of the system. They need to be carefully investigated for the particular application.

The strengths and weaknesses as identified above underline the benefits of using RFID as a technology that can lead to the development of a new buried asset locating system.

This particular research focuses on non-metallic buried assets as these are currently the most difficult to locate using existing locating systems.

2.2 The approach to developing a new locating system

2.2.1 Research aim

The aim of this research is to investigate and evaluate the applicability of Radio Frequency Identification (RFID) technology as a driver of a high definition underground utility mapping system capable of accurately identifying the precise location of non-metallic buried assets.

2.2.2 Research objectives

A set of objectives have been defined which will facilitate attainment, or otherwise, of the research aim. These objectives are as follows:

- To construct a detailed analysis of the body of knowledge on the current approaches to buried asset location
- To evaluate the current approaches and determine their usefulness
- To synthesise the current approaches and develop a route forward for a novel approach using RFID.
- To devise and select an appropriate methodology for the construction of a new system
- To consider and discuss the potential benefits of the new system
- To develop, test and validate a prototype system.
- To develop a framework for an ideal solution for buried asset location

2.2.3 General concept of the locating system

The concept of how to achieve an accurate location of underground infrastructure is presented in Fig. 1.

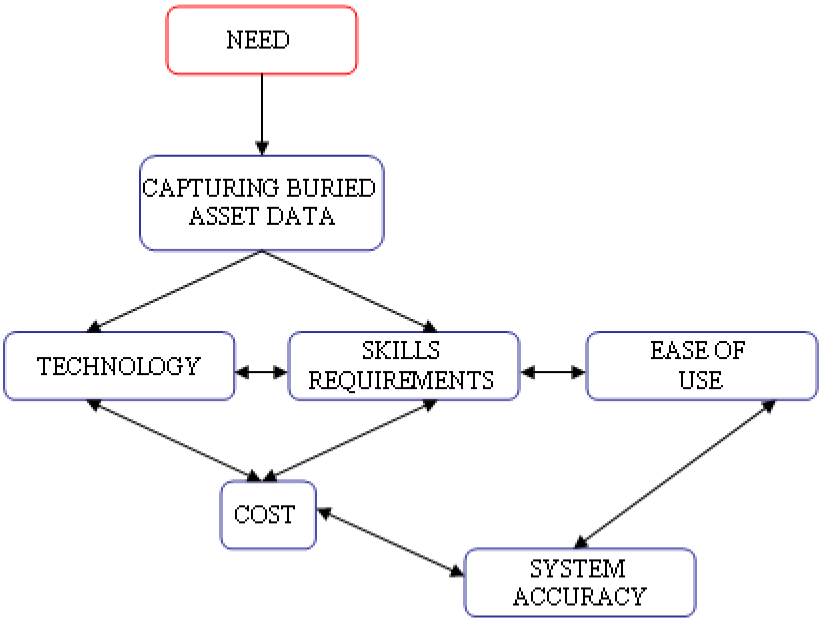


Figure 1. General framework for locating buried services.

This research is driven by the “need” for accurate records of buried services. As previously highlighted in the introduction, 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 (SON, 1999). Existing records very often locate the utility line in only two dimensions (x, y), usually in a form of a line on a map. The third dimension (z), depth, is critically important for the construction of accurate three-dimensional (3D) plans of buried assets (TTN, 2002).

The question is “How to solve this problem and change the existing unsatisfactory situation?” This is difficult, especially when there are so many different locating systems available on the market, each with its own unique features. Unfortunately, none of them possess all of the required features necessary for system accuracy. What is missing is a technology with accurate, three dimensional (3D) ability to capture buried asset data. In order for the system to be functional and efficient a set of specific technical skills would have to be identified. The less complicated the system, the easier it is to implement and operate. More sophisticated equipment or devices will require more specialised skills and so will affect the ease of use, which usually contribute to the overall cost of the system. System accuracy is dependent on the costs and ease of use.

All of the above elements have to be considered when developing an accurate buried asset locating system. These specific elements will be described and analysed in the next section.

2.2.4 Location Operating System

The Location Operating System (LOS) was created to facilitate the connection between the data captured during the fieldwork and its later processing/configuration. The structure of the system including its components is presented in Fig. 2 below.

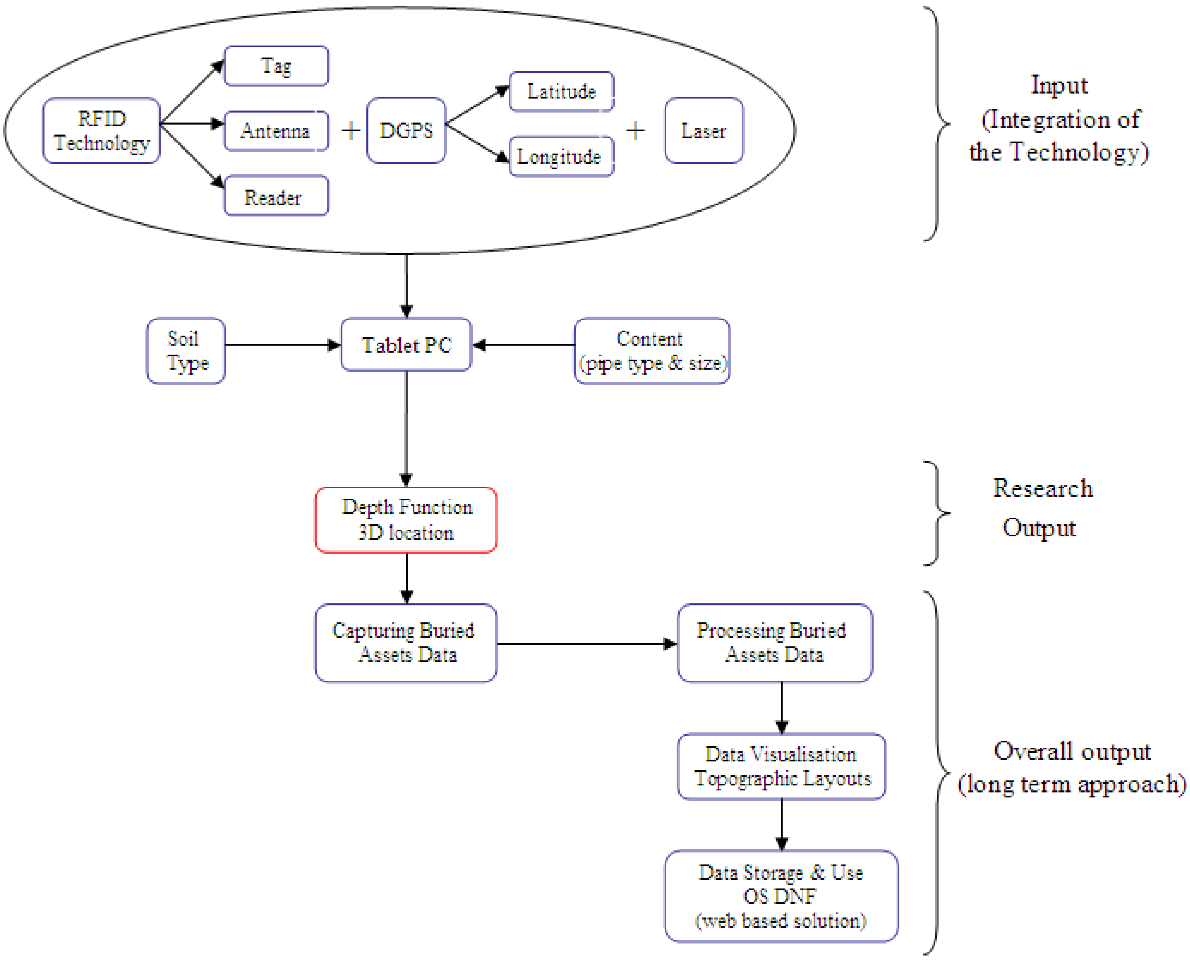


Figure 2. The Location Operating System (LOS).

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 RFID tags, antennae and reader. Laser is used to measure the distance between the ground surface and antenna. A waterproof and portable computer – Tablet/PC, will capture all this information. Integrating and testing RFID, GPS, and laser allow achieving the research output in a format of ‘depth function’, closely discussed in the next section.

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. It has to be noted that the overall success of the LOS system is not possible without developing an accurate locating system.

3. DEPTH FUNCTION

Four different factors that can affect the performances of an RFID-based location system were identified. These factors are presented here in the form of a depth function.

$$d_G = f[(x : content) + (y : tag) + (z : antenna + reader) + (t : soil)]$$

Not all of the above factors may have the same impact on the overall asset location but there are internal relationships between these four factors which mean that changing one of them may require changing another.

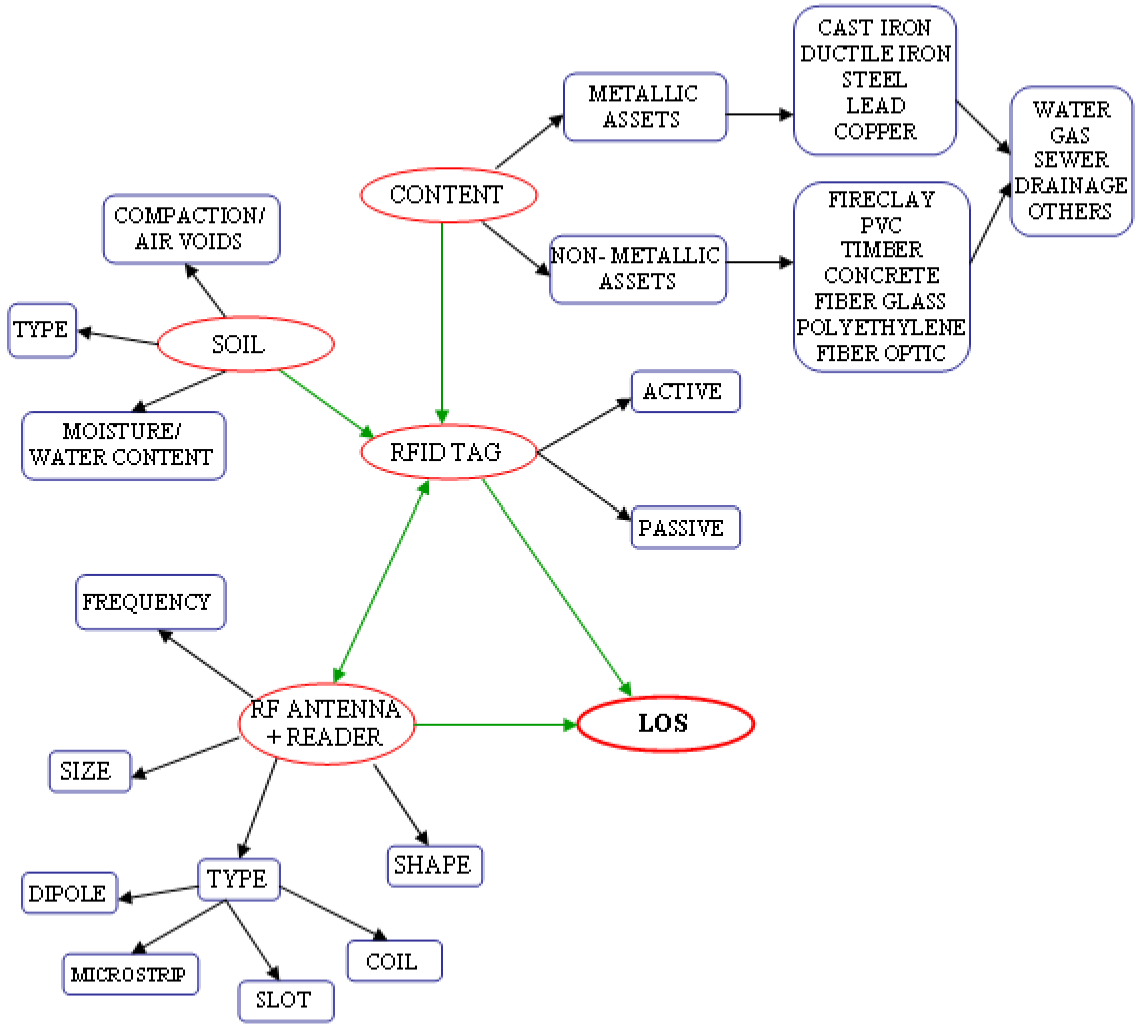


Figure 3. Elements of the LOS.

Each of these four factors has its own list of features and characteristics, as shown in Fig. 3. Because this research is still in a developing stage, not all of elements contained within this figure can be discussed within this paper.

The main factor here is the “content”, which includes type of the pipe (metallic/ non-metallic), its dimension as well as the material in the pipe (water, gas, sewer etc.). The content will indicate the type of the tag that should be used for the particular type of the pipe.

4. RESULTS FROM THE FIELD TRIALS

The experimental part of the research was split into two parts:

1. Lab tests – free air tests
2. Field tests

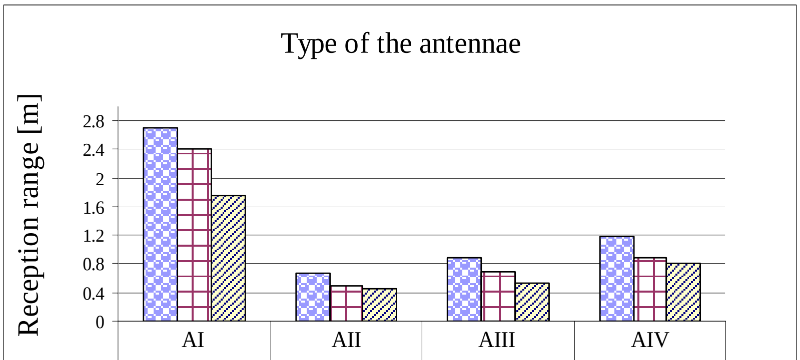
The results of the tests are presented below.

4.1 Lab tests – “free” air tests

“Free” air tests means that the radio frequency RF tags and antennas were not attached to or near any assets or surface that could in any way affect its performance or characteristics.

The main task of the “free” air tests was to establish a baseline for judging the relationship between the RF tags and RF antennae. The Texas Instrument transponders used in this research are passive devices which dose not contains a battery. Energy from the RF reader unit is detected by the transponder and used to provide operating power for the device.

The results from these tests are summarised in Fig. 4. Three tags (LTag, MTag, STag) and four antennae (AI, AII, AIII, AIV) were examined. The goal was to determine an appropriate RFID tag, antennae and reader configuration to ensure that accurate signal indicators, at a range of depths and locations (at up to, and including, 2.0m below surface level) could be secured. This initial configuration leads to developments in the size and shape of receiver antenna in order to achieve the required depth and accuracy.



	AI	AII	AIII	AIV
Ltag	2.7	0.664	0.895	1.185
Mtag	2.4	0.485	0.69	0.885
Stag	1.75	0.455	0.53	0.805

Figure 4. Results from the “free” air tests.

Fig. 4. indicates that the longest acceptable signal reception range can be achieved when antenna AI is connected with Ltag or with Mtag. The tests also revealed 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.

“Free” air tests allow zones of magnetic fields to be created between each of the tags and antennae. These zones determined the magnetic fields within which the technology can operate. With the aid of AutoCAD (design program) and data from the air tests, the range of the signal patterns between all of the antennae and tags were identified.

Fig. 5, 6 and 7 present a range of signal patterns created between antenna AI and tag T2 depending on the antenna position.

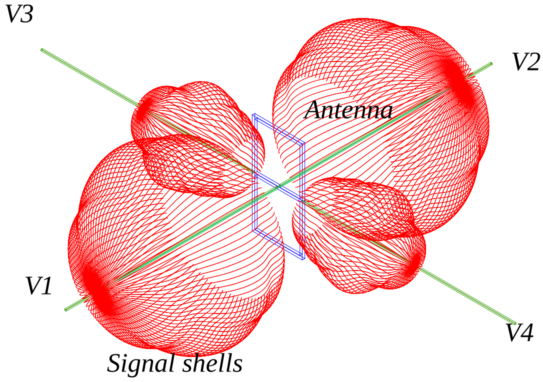


Figure 5. Antenna positioned vertically

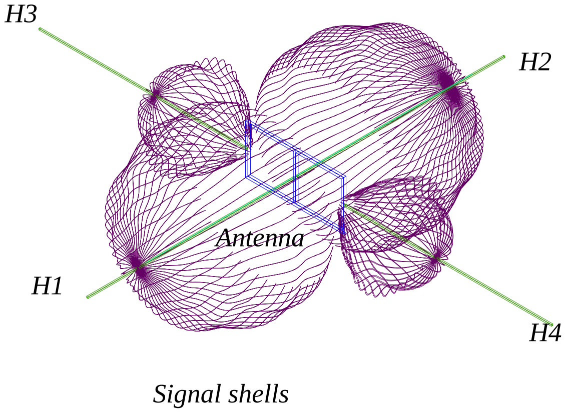


Figure 6. Antenna positioned horizontally

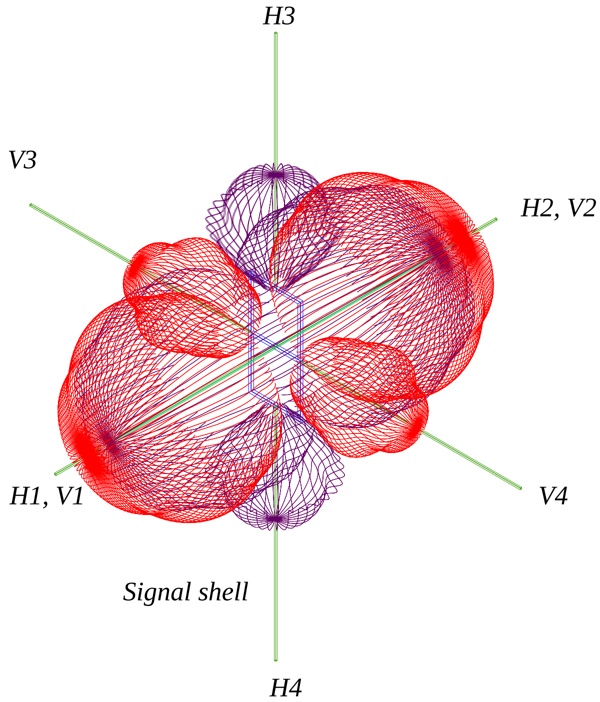


Figure 7. Superimposed reception shells

In Fig. 5 the antenna was positioned vertically. There are two sizes of shells; with the bigger shells lying 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 signal generated by the tag.

Fig. 6 shows the antenna in horizontal orientation. The description is similar to the one given in Fig. 5. Again we can observe two sizes of the shells which show the reception range of the signal in this orientation.

Fig. 7 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.

Assuming that radiation field strength remains unchanged regardless of the environment it would be possible to develop software that can calculate the depth and ground location of buried assets.

The aforementioned software would accept three coordinates, all of which would have to be points on the outer edge of the signal shell. These would be found by moving a mobile antenna and GPS tracker along the ground at a set height (measured by laser). Where the antenna begins to pick up a signal (or ceases to receive a signal) GPS positions would be noted. Three GPS references would be acquired: Pin1, Pin2 and Pout as shown in Fig. 8. These points would be signal shell entry and exit points at a specific height, forming a triangle from which simple calculations (the theory 'circumcircles of triangles') will give us the absolute centre of the shell (i.e. a point directly above the buried tag). Having accepted the three references, the software would provide the user with the GPS location of this centre point (C).

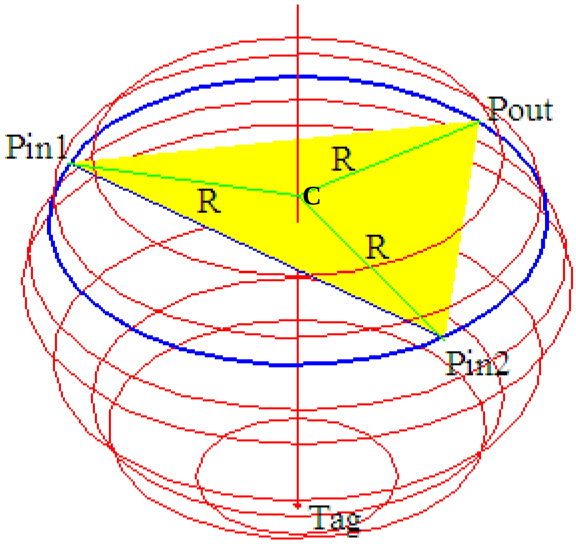


Figure 8. Tag position.

Having found the position C of the tag in terms of longitude and latitude, the depth can be calculated.

The antenna should be positioned at GPS location C. The antenna should then be raised until the point where it is found to leave the signal shell (Fig. 9). The height (Z) above ground at this point should be measured by laser. Since total height of the signal shell (H) is known, we can specify the depth of the tag below the ground (D) as H minus Z.

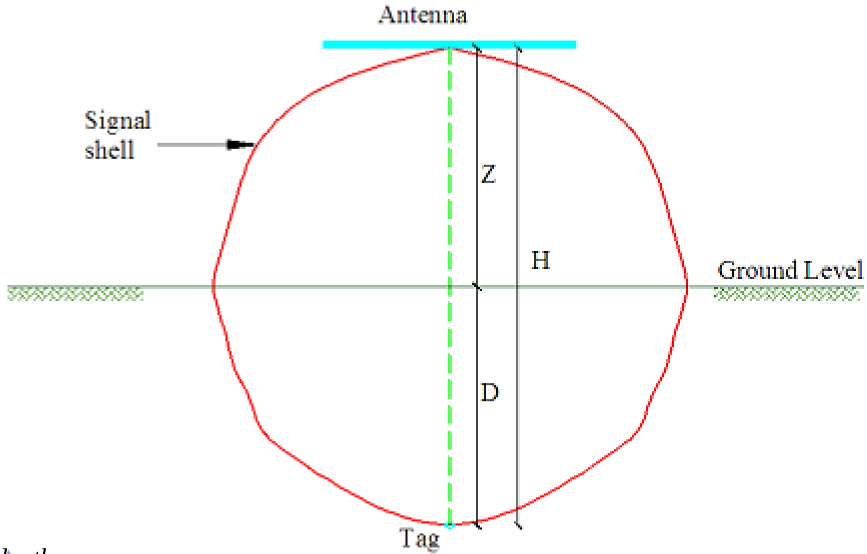


Figure 9. Tag depth.

4.2 Field test – Real implementation

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 by the use of laser. The ground distance (depth) of a tag was possible to determined using the following trigonometric equation, presented in Fig. 10 below.

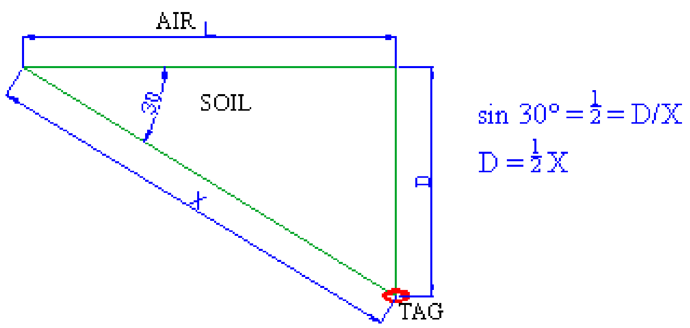


Figure 10. Trigonometric function.

Using this equation it was possible to simplify the process of locating the tag and consequently the depth of buried pipe.

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

An implicit part of the investigation was aimed at ascertaining the extent to which soil conditions affect the reception of the reading signal. In order to examine these two further tests were carried out:

- the separation between the tag and antenna was only soil (Fig. 11)
- half of the distance was in soil and the other half was air (Fig. 12)

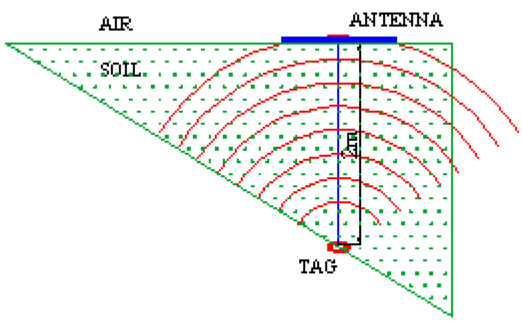


Figure 11. Only soil

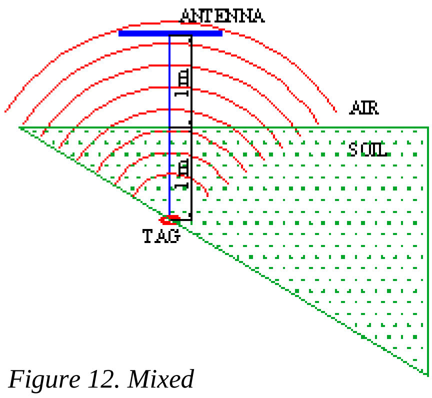


Figure 12. Mixed

Fig. 13 presents the maximum reading distance achieved during the field tests for large (Ltag) and medium tag (Mtag) in conjunction with antennae A1 and A2.

After comparing the field tests results (Fig.13) and the “free” air tests results (Fig.4) it was discovered that the presence of soil during these tests does not affect the overall performance characteristic of the system.

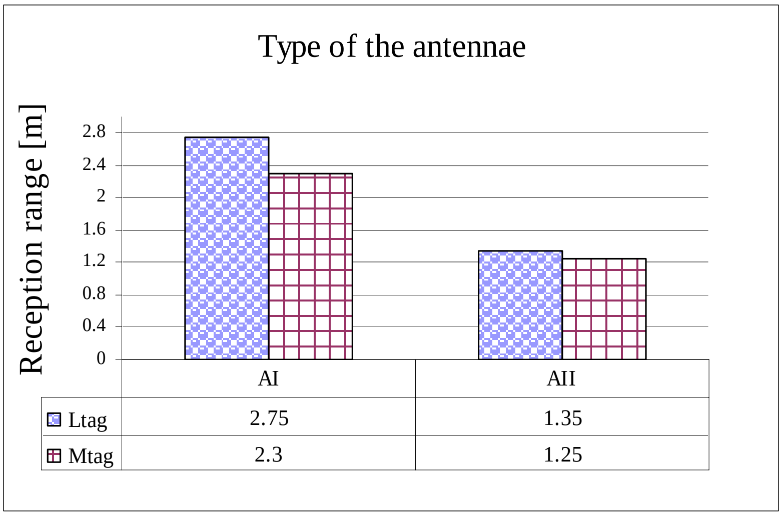


Figure 13. Results from the field air tests.

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 and it is possible that different soil types and conditions can affect the signal range (Jarvis, 2004).

To assure the accuracy of the initial results additional tests in different soil types and under variable conditions are required.

5. CONCLUSION

The problem considered in this paper drives the desire for a robust buried asset locating system and therefore the overall data management of underground infrastructure. A new approach to buried asset location system based on RFID technology was introduced and its ability to enhance the location of underground infrastructure was investigated. A necessary model (concept) that allows for locating buried assets was also presented.

The “free” air tests show how the tags perform under ideal conditions, and as all environmental factors were controlled, any differences in performance can only be attributed to the design and construction of the tag. Additionally, “free” air testing reveals how tags will perform around “RF-friendly,” materials or environment.

The tests also reveal that the orientation of the tag with respect to the RFID reader influences the energy absorbed by its own antenna. Depending on this angle, the energy will vary and sometimes may not be high enough to power the chip inside the tag, resulting in the reading signal being out of range. That is why it was important to identify the signal shells and its range.

Part of the ongoing work is to create software based on Figs. 2 and 3. The main structure of this approach was presented in Fig.2 and the components related to capturing buried asset data were identified in Fig.3. Further work will focus on linking the data captured and the data processing system, using the Digital National Framework (DNF) compliant Topographic Map overlay and storing the data in the Ordnance Survey (OS) DNF format. It can then be accessed and data mined by utility companies.

The system is still in its evaluation stage and additional amount of tests and experiments will have to be carried out to achieve conclusive results. So far, the basic experimental results suggest that it is possible to accurately localise buried assets using RFID devices but a considerable amount of development work is still to be done to arrive at a fully operational system.

One of the biggest benefits that the use of RFID technology can bring, if properly implemented, is that it can reduce the time required for actual buried asset localisation and also reduce the level of skill requirements of the operatives.

It is clear from this research that through judicious use of RFID technology, the current unsatisfactory methods for locating buried assets can be improved upon.

6. REFERENCES

Booth S (2005). *Coordinated utility services: pipedreams or a geospatial future?* Geomatics World.

Cumberbatch S (2005). *What lies beneath?* Surveyor, SVY0505 p.14-15. www.surveyormagazine.com

Finkenzeller K (2004). *RFID HANDBOOK: Fundamentals and Applications in Contactless Smart Cards and Identification.* Second Edition, England, p25-26.

Irrigation Training and Research Centre, Report No. R03-010, (2003). *http://www.itrc.org/reports/aewsd/undergroundpipe.pdf*

Jarvis, M G. *Soil Information and its Application in the United Kingdom: An Update.* Soil Survey and Land Research Centre, Cranfield University, Silsoe Bedfordshire, MK45 4DT, UNITED KINGDOM.

MedicAlert Technology (2005). Wireless network, U.S.IT& Telecom Update. *The case of RFID and the Retail Supply Chain*.

MICROLISE, (2002). *Consideration for Successful RFID Implementations.* http://whitepapers.zdnet.co.uk/0,39025945,60089849p-39000532q,00.htm

UK Water Industry Research Limited, (2006). National Underground Asset Group. *Capturing, recording, storing and sharing underground asset information – A review of current practice and future requirements.*

Statement of Need (1999): *Utility Locating Technologies*. http://www.nal.usda.gov/ttic/utilfnl.htm

Trenchless Technology Network (2002). *Underground Mapping, Pipeline Location Technology and Condition Assessment.* The University of Birmingham, Infrastructure Engineering and Management Research Centre.