Intelligent wireless asset tracking of packaged gases

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Abstract. Gas cylinders are used in many different situations, such as in research, in industry, in healthcare, and even in the home. Due to demand in such a wide variety of circumstances, there is the inevitable ambition of gas suppliers to improve the efficiency of their business. To this end, a tracking system is proposed in this paper in order to provide such improved efficiency whilst also integrating sensors in order to monitor gas cylinders from a safety perspective.

1. Introduction

Asset tracking is an essential part of many industries, in particular, those concerned with logistics, purchasing and manufacturing. In recent years, automated identification systems, especially Radio Frequency Identification (RFID), have been identified as having huge potential to improve the effectiveness of asset tracking in general. The term ‘RFID’ has become synonymous with a particular type of radio frequency identification method, which involves the use of ‘tags’ to store data and ‘readers’ to acquire this data from the tags. Systems such as these have been used for many years in applications such as animal tagging [1] and road toll collection [2].

Since RFID utilises radio waves for identification, tracking can be contact-free, without requiring line-of-sight as with other systems such as barcodes. Gas cylinders offer a scenario where automated tracking is difficult to achieve, however. The cylinders themselves are generally quite bulky and heavy whether full or empty. It is easy for cylinders to rub against other objects, such as their storage container wall or even other cylinders and so tracking tags (such as barcodes) attached to the sides of the bottles could be easily damaged. In addition the highly metallic environment ensures significant RF signal attenuation – this in turn makes it extremely difficult to track gas cylinders using traditional RFID techniques (i.e. – ones where communication may only take place directly between a ‘tag’ identification device and a ‘reader’, which obtains data from suitable tags). New techniques [3-4] are seeking to overcome obstacles which have generally limited the use of automated identification in asset tracking when certain conditions or environments present themselves; this paper considers one such technique in the form of Wireless Sensor Network (WSN).

The remainder of this paper takes a brief look at the technology being investigated in order to achieve tracking of gas cylinders. An early prototype system is presented and the idea of an unmanned gas cylinder storage facility is discussed. Finally, some attention is paid to the expansion of this
system to include intelligent sensors, which could provide useful real-time data to enhance the safety of gas cylinder storage and usage.

2. The Tracking Technology

As previously mentioned, RFID is not a particularly new idea; its roots lie as far back as World War II, and the first patent for the technology as it is generally used today was made in 1973. There is no one set way of achieving RFID however. In theory at least, any technology, which is capable of identifying itself uniquely via radio waves, can be used as part of a radio frequency identification system.

The past 5-6 years have seen significant leaps in the technology available to facilitate the use of WSN. The *motes* [5] (see Figure 1), which make up the sensor networks can be said to have intelligence since they are expandable to provide interfaces to the outside world via sensors, and they are also fully programmable which enables them to respond appropriately to environmental stimuli. Programmability is assured through the devices having their own operating system, which not only allows programmers to take full advantage of the hardware available (e.g. – ADC, microcontrollers, RAM, non-volatile storage, wireless communications), but also ensures the most effective use of the limited battery power available.

Another key feature of motes is their ability to communicate with each other wirelessly to form ad-hoc networks. These networks allow for a multitude of tasks to be undertaken, from simple data transfer to inter-device collaboration for a truly intelligent network.

![Figure 1. (left to right) Micaz (2.45GHz), Mica2 and Mica2Dot (915MHz) motes](image)

Whilst these features are impressive for such small and capable devices, it is important to identify the key aspects of these features, which give them an advantage over traditional RFID systems whilst also acknowledging any weakness, which may have to be overcome.

- **Range:** Motes are able to organise themselves into an ad-hoc network. Using this network, messages between motes, which are not in direct communications range, can still be sent and received successfully via intermediate motes; this phenomenon is often referred to as *multi-hop routing*. This can allow motes to operate in harsh RF environments provided they are clustered densely enough to overcome the signal attenuation caused to individual devices.

- **Expansion:** As previously mentioned motes may be expanded to include sensors – current examples include light, temperature, ultrasonic and even GPS receivers. When applied to the idea of asset tracking, such features could prove invaluable in quality assurance, for example, as it could be possible to monitor the condition of assets throughout the supply chain.
• **Scalability**: This refers to the ability of some application or technology to meet the growth requirements of, for example, a supply chain. When applied to WSN, this means that the technology is required to work whether there be 100 items to track or many times that. Since motes are programmable, it is fully feasible to implement network protocols, which cater for large amounts of devices being present in a confined space.

• **Power**: At the moment the options for powering motes are quite limited, and generally a battery power source of some sort used. Figure 2 illustrates the voltage decay of a Mica2 mote’s battery power supply over a period of 150 hours with and without power saving enabled. The difference is rather drastic and means that with a duty cycle of around 1%, a mote can operate for 15 months on a single set of 1500mAh ‘AA’ batteries.

![Figure 2. Mica2 mote battery voltage decay over 150 hours](image)

3. **Prototype System**

Before considering the full implications of how WSN could fit into a gas cylinder asset tracking system, it was vital to consider the feasibility of the technology in a small-scale environment. From such an environment the aim was to discover whether or not communication between motes was possible and reasonably reliable despite signal attenuation, which inevitably would be caused by the metallic surroundings.

To this end, a prototype system was developed and tested to investigate the performance of a small number of motes in a simulated asset tracking environment containing caged gas cylinders which are stored outdoors. Each of the four cylinders used during testing had a Mica2 mote securely attached to its collar via a nylon cable tie, with each mote arranged randomly in order to create situations were motes are in non-line of sight (NLOS) conditions, were antennas are in various orientations and even were antennas are touching the metal gas cylinders. Ultimately, each of these situations was designed to reproduce a worse case scenario for RF communications.

Indoors, a computer with software designed specifically for this test had the network addresses, or IDs, of the four tags stored in a database and arbitrarily associated with a particular type of gas (e.g. – Nitrogen, Oxygen, etc). Attached to this computer was a mote base station – sometimes referred to as a sink node – which acts as a portal to interface a PC with the sensor network. In order to ensure reliable communication between the base station and the motes attached to the gas cylinders outside, and to simulate a real environment, intermediate relay mote was used. This was placed outdoors...
approximately 10m away from the gas bottles – in reality this would be a node place near to a cylinder enclosure and used as a data router. Between this relay mote and the base station was a brick wall. An overview of the experimental setup can be viewed in Figure 3.

The results of testing this system were very optimistic; it was found that the motes were able to communicate reliably, despite their harsh environment and numerous random arrangements of motes on the gas cylinders. Not only was it possible to determine which tags were active at any one time (either all of the tags, or selected subsets such as all Oxygen cylinders), it was also possible to communicate with individual tags via their unique network address in order to trigger an event – in the case of this test, this involved the sounding of a speaker attached to each mote. In reality this two-way communication could be a request for the tag to identify itself or to provide some sensory data.

4. The Automated Gas Storage Facility

The idea of the automated gas storage facility is for it to be an expansion from the prototype system setup. Instead of there being only four gas cylinders, there may be hundreds or even thousands. In addition, the gas cylinders would be in motion when being picked up or dropped off by (or for) customers, and so the system would have to be expanded to handle this sort of situation. However, it has already been established that WSN offer a great deal of scalability and can operate in a static metallic environment, and so it is feasible to suggest that there is potential for the technology to be applied as a large scale tracking system.

The facility itself would be unmanned (largely at least), a place where gas cylinders could be picked up and dropped off whilst the facility itself keeps track of stock without human intervention. Figure 4 shows a simplified overview of such a facility.
Deliveries to customers may be achieved in a number of ways; for example, they may pick up cylinders themselves or the facility may have dedicated drivers to make deliveries. In order to gain entry to the facility some sort of automated identification could be used. Upon entry, motes attached to the cylinders can be interrogated in order to identify them (i.e. – their contents, from whom they are being returned, etc). Rather than each mote having to communicate back to a single ‘reader’ device however, data can be hopped via the motes on other cylinders and so problems with signal attenuation can be negated. At this point, depleted gas cylinders can be dropped off to be filled up again at some later date and new bottles may be collected. Relay nodes may be located around the facility (see Figure 3, where such devices have been used) in order to determine where cylinders have been placed and which ones have been removed. In addition, the cylinders can once again be interrogated upon leaving the facility; if a customer was collecting cylinders themselves, then any detected could be charged to their account.

**5. Sensor Expansion**

There are a number of possibilities for sensors, which could enhance the safety of storage and use of gas cylinders and be integrated into the proposed tracking system. One such suggested sensor would be a pressure sensor, since this could be connected to a mote and monitored to establish the amount of gas in a cylinder at some point in time. A potential advantage of having this information would be to provide a user with information regarding the amount of gas left, and in large institutions an event could be triggered to automatically order new stock of a particular gas. In addition, this could be used to monitor for leakage, primarily in the automated gas cylinder storage facility. A build up of leaking...
gas could lead to a scenario were an explosion occurs – a pressure sensor could detect the drop in pressure as gas escapes from a bottle and trigger an alarm for action to be taken.

In addition to pressure sensing, an accelerometer could be used to detect the orientation of a gas cylinder. This could be useful in instances where cylinders have been knocked over in the storage facility; this could be a hazard in itself if the cylinders are loose to move around and become damaged. It could also be useful for particular types of gases, such as acetylene, which is used in oxyacetylene gas welding and cutting since it can produce a very high temperature flame. Acetylene is highly unstable and can explode if compressed [6] – as a result it is shipped in a metal cylinder with a porous filling and also dissolved in acetone in order to make it safe to transport and use. The tanks themselves must be kept upright when used, and also left upright before use for up to an hour or else the acetone may be drawn into the regulator. An accelerometer which is used to monitor the orientation of a gas cylinder could warn the user if the bottle is or has been recently stored in a horizontal position, and could even be coupled with an over-ride system to prevent usage until an appropriate time.

6. Conclusions

This paper has presented a prototype gas cylinder tracking and monitoring system along with idea for further expansion of such a system, which is based around WSN. The prototype system proved reasonably successful, and this means that further tests are feasible in order to quantify the losses and attenuation suffered by the motes as a result of the metallic environment. In addition it has been proven that the motes can be used without replacing their power source for approximately 15 months, and in coming years there may even be the possibility of using alternative power scavenging techniques [7-8].

Further work is currently being undertaken in order to increase the usability of WSN in an asset-tracking environment, in particular:

- Inclusion of a discrete antenna to prevent mechanical damage which is possible with a simple monopole
- Data routing protocols will be implemented with the intention of extending battery life as far as possible whilst maintaining low levels of data loss and ensuring network scalability for a real-life asset tracking environment.
- Consideration of asset management as part of a larger transaction management system which not only tracks actual assets but links data with regards to stock purchasing, customer orders and invoicing as well as being able to perform asset inventory and tracking tasks.
- Cost needs to be dramatically decreased from the order of $65 (plus the cost of power replacement every 12-15 months) to nearer $5 or less. This is feasible in a number ways, for example, the ‘mote’ could be redesigned to use cheaper and fewer components (e.g. – utilise combined integrated circuits for both processing and radio such as the Chipcon CC2431 [9]) whilst also being produced in large quantities to further reduce cost. It is important to remember however is that gas cylinders are reusable many times over and so the mote tracking devices would not be discarded as single use; they could stay with a cylinder for its entire usable life and possibly even be re-used should a cylinder require replacing.

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