Resubmitted to IEEE Concurrency, July 2000

Ubiquitous Electronic Tagging

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ABSTRACT

The automatic identification industry is growing rapidly. Machine-readable tags occur in many forms and appear on everything from luggage at the airport, to dogs, trains and fresh fruit. Electronic tags are a subset of this market with the potential to revolutionize the tagging industry. As with many advancing technologies, there are a variety of tagging standards that do not inter-operate and thus hinder widespread deployment, and hinder the creation of applications that could take advantage of tags used by a variety of industries.

This paper examines the applications and consequences of Ubiquitous Tagging, the technology currently available to build it and some future technologies beginning to emerge, which could turn 'Ubiquitous Tagging' from a nascent technology into an industry wide feature of modern manufacturing.

At the end of the paper, we close with a discussion of several concurrency issues that ubiquitous tagging brings to the fore.

KEYWORDS: electronic tags, active tags, passive tags, RFID, inductive coupling, capacitive coupling, barcodes, Taggants, privacy.

INTRODUCTION

The trend in the growth of automatic identification technology is inescapable: electronic machine-readable tags (e-tags) are becoming tiny, cheap and easy to deploy. Not only can a modern e-tag uniquely identify the object it is attached to, but it can also serve as a data repository for that object. Imagine if every object ever processed had one or more machine-readable tags embedded into it. What applications would that enable? These tags would uniquely identify the object and be readable from a distance, not even requiring a battery. We discuss the technologies that will make this possible. In addition to identification information, e-tags can record their history, or offer dynamic data from an embedded sensor indicating, for example, the tag's temperature. Modern technologies will evolve simple e-tags into complex microcomputers, which can communicate with both readers, and other e-tags, radically changing the notion of what a tag is and the functionality we expect from it.

WHAT IS A TAG?

A tag is any device, or label, that identifies the host to which it's attached. It typically does not hinder the operation of the host, or adversely affect its appearance. However, once attached the tag enables the host object to be more easily and accurately identified. Electronic tags are simply machine-readable (possibly writable) tags.

Object identification can be established at various levels of detail. A tag could contain a unique serial number, or it could describe a generic product, such as a battery type (AA or D cell). Tagging can be achieved in many ways and objects at different scales may need to use different technologies, or materials, to achieve the required behavior.

For instance, at the nano-scale individual atoms can be tagged within a molecule by replacing them with their radioactive isotope. Organic chemists regularly use this technique to examine the underlying mechanisms for organic chemical reactions. For example, when two molecules react and both contain oxygen atoms, how do you know where their respective oxygen atoms have been located, after the reaction products have formed? By repeating the reaction with radio-labeled atoms at differing positions, the new locations can be determined.

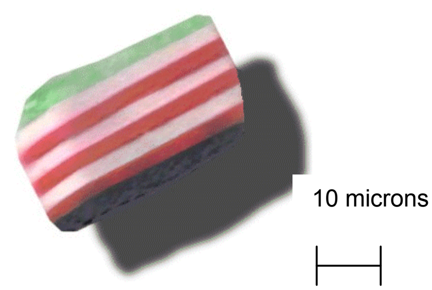

Figure 1 Taggants are small pieces of plastic with unique microscopic sequences of colored bands.

However, in our everyday environment radioactive labels are undesirable for obvious health reasons. Chemical labels are the next best thing, and have good commercial application, for example in the explosives industry. Most of the major explosive manufacturers tag their products with thousands of resilient plastic tags called Taggants [23].

Each color sequence can be mapped to a serial number, and is traceable to a particular batch of the product and hence to the customer, see Figure 1. The plastic fragments are very tough and will mostly survive the force of a blast when the explosive is detonated. The consequence is that a blast site will now be covered with Taggants, and in the case of a terrorist attack, there is now a direct link to the explosive's manufacturer and to whom they were sold

Specialist tags, such as those described above, have very specific uses and are not designed to be easily readable by conventional electronic means.

An extreme example of tagging is to consider the DNA sequence of every living thing as a unique identifier. The genome is replicated in every cell of an organism, and if cells are damaged, the code is further replicated in the new cells that grow to take their place. Most animals continuously shed dead cells from their skins and therefore leave a trail of tags behind that is more specific than any scent. However, with today's technology, the apparatus required to read or even characterize a DNA sequence from a sample is bulky, complex and very very slow. DNA is not a good option for general purpose tagging, but DNA sequencers are improving and one day might be sufficiently rapid for on-the-spot identification purposes.

From an information processing perspective, tags which have been specifically designed to be read reliably and quickly are considerably more useful in day-to-day applications. Another key factor for the usability of a tag is the form factor of the reader. Tag readers must also be of a reasonable size and cost.

Current automatic machine-readable tags can be categorized in the following way:

Passive (no battery)

- Optical (barcodes 1D and 2D [3], vericodes, glyphs [5])
- RFID (inductively coupled [1, 2, 9], capacitively coupled [8])
- Contact tags (silicon serial numbers, ibuttons [4]).

Active (battery or a local power source is required)

- Transponders (Aeronautic IFF systems [13], Portable Information Appliances [20], and Smart Cards [6]);
- Beacons (Active Badges [19], Loran or GPS Navigation)

Barcodes are today's de facto standard for automatic identification. The UPC (Universal Product Code) label can be found attached to most of the products we buy at the supermarket, and they benefit both the consumer and the store [17]. The former experiencing less time at the check out and the latter not only having the potential of greater customer throughput, and hence profit, but also a mechanism for automatically updating an inventory database and reordering stock.

Traditional barcodes and their modern counterparts such as 2D-codes, block codes (vericodes) and glyph codes are passive optical codes [3, 5]. The main strength of optical codes is that they are very inexpensive, costing no more than the application of printer's ink, or in the case of laser printing, applying toner to paper. They also require no battery. The weakness of printed optical codes is that they are notoriously unreliable in conditions other than in clean indoor environments and on surfaces that have smooth flat contours. Barcodes suffer from the following common problems:

- Dirt build up (particularly oil and grease)
- Ink bleeding
- Label distortion (e.g. from curves on a flexible surface)
- Tearing
- Difficulty reading in bright light or direct sunlight

It is also a limitation, that they cannot be easily modified, appended to or erased. They take up real estate on the exterior of a product and have an aesthetic that most marketing departments have unwillingly learned to tolerate. Finally, barcodes are easily forged. Removing a tagged label and applying a tag belonging to a lower priced product can result in under pricing and product theft.

ELECTRONIC TAGS

There are many types of electronic tagging alternatives that improve the undesirable properties of barcodes, while maintaining their 'read at a distance' characteristic. RFID (radio frequency identification) is the most common, and an intriguing technology, because it contains no internal power source, and instead, power is transmitted from the reader to the tag. Once the tag is powered, an electronic circuit becomes operative, which in turn sends a signal back to the reader. There are two mainstream approaches that have been exploited in the design of RFID tags: inductive coupling and capacitive coupling.

Figure 2. A Trovan RFID tag [base] weighs from 0.1 (grain of rice size) to 7 grams (credit-card size), and contains a 39-bit unique identifier.

INDUCTIVELY COUPLED RFID TAGS

The majority of commercial tags depend on inductive coupling. These tags are made from a coil, a silicon chip and an encapsulating medium for protection. Power is transmitted from the reader to the tag via electromagnetic induction. Data is transmitted from the tag to the reader by load modulation of the tag's coil in a pattern determined by the silicon chip (data can also be send from the reader to the tag through a similar process). A well-known RFID tag manufacturer is the German Company, Trovan [16] - see Figure 2. Here we show (base of figure 2) a glass-encapsulated version of the smallest Trovan tag. These tags have 39-bits of user data, allowing 550 billion objects to be uniquely tagged. The read time is about 100ms and the read distance is dependent on the size of the interrogator antenna: typical handheld readers can determine an ID at a distance of 5cm. A large reader can locate a tag up to 2 feet away. The interrogation frequency used in this system is 128kHz and represents the lower frequency end of the spectrum used by RFID. The choice of a relatively low frequency has consequences. Firstly, non-metallic materials do not absorb it very easily and as a result a tag can be embedded below the surface of a product's case or packaging and still be read effectively. The downside is that the typical inductor required for a tag antenna has a large inductance and hence many turns of copper (as many as 200 turns). In addition, the wire gauge needs to be sufficiently large to ensure the DC resistance is small, resulting in a parallel resonant circuit that has as large a Q value as possible. It turns out that a large fraction of the cost of a tag is in the coil antenna and the winding process. In a bid to reduce costs and to increase the data transfer rate to, or from, RFID tags, alternative designs have been sought.

Figure 3. Texas Instruments: Tag-it system

A more recent design approach has lead to an industry standard for a higher frequency tag operating at 13.56MHz. This allows for a smaller inductor to achieve the desired resonant frequency, and thus with 10-20 turns, the high Q value can be achieved more readily. With a smaller number of turns the coil is more easily fabricated from a surface lithographic technique and thus RFID tags can be created in the form of planar labels with an aluminum spiral coil on acetate and flip-chip at its center. The TIRIS (Texas Instruments) Tag-it system [15] is an excellent example of this implementation (see Figure 3).

An additional feature of this system is that it has been designed to allow multiple tags to be read simultaneously while in the vicinity of the reader. The Trovan system will only accurately read one tag at a time. If multiple Trovan tags are present, typically the closest tag wins out, although if tags are in varying orientations this may not necessarily be the case and cannot be relied upon if guaranteed differentiation is required. Trovan tags equidistant from the reader will generate signals that collide with each other resulting in garbled data. The Tag-it system, however, uses an anti-collision algorithm to limit data corruption, and if the read process is repeated, eventually all the tags that are in range will be read. The details of these techniques are beyond the scope of this paper but can be found in detail at the www.tiris.com web-site. The TIRIS Tag has additional functionality in that data may be written to, or read from, a 256-bit non-volatile memory. This allows Tags to represent a considerably larger tagging space than the Trovan tags previously described (an unimaginable large number) and as the data transfer rate is also at least a magnitude larger at 9kbps, the read time for all 256 bits is very similar, to the 39-bits of the older technology

CAPACITIVELY COUPLED RFID TAGS

From an engineering perspective, the complexity of a tag's operation has largely been determined by the limitations imposed by state-of-the-art semiconductor manufacturing techniques. The silicon industry is currently following Moore's Law [12] which predicts for a given area of silicon, the number of active devices will double every 18 months. A direct consequence is that for the same available energy you can power more transistors on the same piece of silicon as each year goes buy.

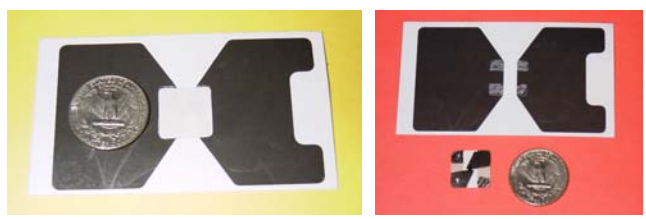

Figure 4. BiStatix Capacitive Coupled Tags (Indala)

Motorola BiStatix tags [8] represent a radical departure from the traditional inductively powered tag design. In Figure 4, two views of a tag can be seen. There is a great deal of similarity with conventional RFID since the tag consists of an RFID chip and an antenna, which in this case is made from two plate electrodes. The reading mechanism between the reader and the tag is through capacitive coupling. The tag is powered by placing the tag in an electric field. The field gradient across a tag results in a charge build up between the plates, and hence a potential difference, and this is used to energize a small silicon chip at its center. Modern high-density CMOS lithographic techniques have resulted in silicon devices that can perform an identification function and only require about 25 micro-watts of power: a level small enough that the electrostatic field gradient across the tag is sufficient for the purpose.

One of the most attractive features of this novel design is that the resistance of the antenna is no longer a critical factor and may be constructed from materials of considerably higher resistance than used in the inductive technology. Tags have been shown to be operative at 700ohms/sq. In particular, this means that conductive inks, which have a moderate resistance, can be used to form the antenna. These inks are no more costly to produce than conventional printer's inks, and thus in relation to the cost of barcodes, the increase in cost is the small piece of flip-chip silicon than is needed to support the tag's operation. As lithography becomes even more advanced, the silicon component will shrink in size, as will its cost and the operating power.

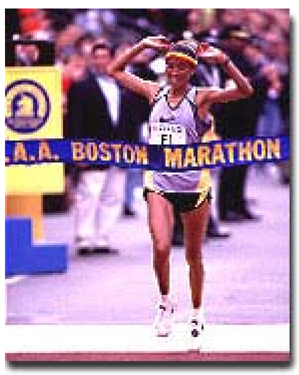

Figure 5 Boston Marathon runner wearing a TI tag laced into shoelaces. Barely perceptible at 3.8 grams, the tag creates an accurate timing for each runner, from the read-event at the start line to the read-event at finish line.

CONVENTIONAL USES OF ELECTRONIC TAGGING

RFID tags have been used in industry for some time. One of the first uses was to keep track of cows by placing an RFID tag under the hide. A farm is such a dirty and harsh environment that conventional barcode technologies would not survive more than a short period of time. This allowed farms to set up automatic feeding stations without the danger of over feeding any particular member of the herd, something cows are likely to do if not checked. Automatic identification also enabled medical data, such as inoculation records, to be made available on an automatic basis. RFID has also been used to provide secure access to government institutions, and the US railroad has adopted them to track its rolling stock since 1977. The automobile manufacturing industry tracks car body parts using specialized RFID tags that can withstand up to 200C inside a paint oven. These are all applications in which the environment is harsh or security (creating obstacles to counterfeiters) is a premium. Under these conditions the additional benefit of RFID technology, out weighed its additional cost. More recently, new uses of RFID have been to track runners in a road race. Figure 5 shows a finisher being automatically time-logged in using the TI Tag-it technology at the Boston marathon 1999. Costly office computers are also candidates for e-tags, and RFID tags are now being used as part of IBM's *AssetID* program for location and management of these valuable assets [7].

Mobil Oil has begun offering drive-up service at their gas stations in Singapore based on TIRIS e-tags. A motorist is able to drive to a pump, and be automatically identified (along with their credit card) through a vehicle-mounted e-tag. This read-event uniquely identifies the customer and speeds up the normal credit checking process (www.tiris.com).

CONCURRENT TAGS

When many objects are tagged, issues arise with respect to sensing and using the tag data. As shown in Figure 6, moving a tag near to a tag reader causes a read-event to occur. When many tags are being read simultaneously (as when many runners cross the marathon finish line, or an entire basket of groceries is being read at once), the events must be serialized. As mentioned earlier, many RFID tag-sensing methods respond only to the closest tag, so physical methods, such as forcing object flow through gates to sequence the events, is one solution. When optical barcode tags are used, additional careful orientation is needed to pass everything properly in front of the scanning system.

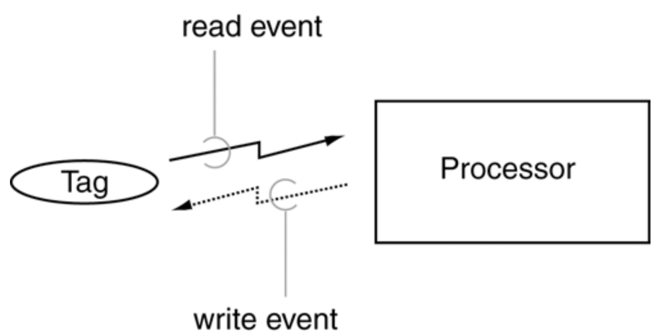

Figure 6 A tag entering the reading field of an interrogator, or processor, gives rise to a read-event. Some tags may also be written to with a limited amount of data.

But an important goal for many applications is being able to read a large set of tags without requiring difficult physical manipulations. Although some anti-collision mechanisms are used in newer products, such as TIRIS, we expect to see advances in the techniques used to achieve concurrent operation. These include novel approaches that utilize scanning (e.g., sweeping through a range of identities, and monitoring for replies), and a method of spreading the spectrum of replies (e.g., each tag transmits on a slightly different frequency, or CDMA). A more radical approach might be to use tag-to-tag data hopping to transport a set of unique identities through an ad hoc network of tags. A simple algorithm would involve e-tags contacting their nearest neighbors and agree on a reply sequence based on the ordering of their unique serial numbers. In this way, tags in an ad-hoc group can concurrently determine a serialization sequence for delivering their collective contents.

ACTIVE OPTICAL TAGS

Optical tags have always had the potential for concurrent reading. In daily life we routinely read the labels printed on multiple objects in our field of view without difficulty. This is hard to do using a computer vision system (camera, image capture card and a computer). However, through the custom design of an active optical tag, it is possible to make the parallel identification process very simple. By spatially multiplexing many tags with a unique encoding it is possible to speedily read the data from all the tags. Moore [11] describes how a time sequenced flashing LED can be used to send data from many tags in the camera's field of view at half the video frame-scan rate. IR LEDs are used because it is invisible to the human eye, but stands-out for a CCD camera. Multiple LEDs can be associated with a single tag to multiply the data-rate to a desired value. This is a powerful design approach for electronic tagging in situations in which the tags are visible. However, in many real-world situations the tags may be obscured, in which case RFID is a more appropriate solution.

If a special purpose IR receiver can be built, IR signals can be modulated to convey information in a more concise format. This is the principle by which the common TV remote control operates. A device that emits a uniquely modulated IR signal, either as a beacon or in response to a trigger, can also be used a tag. Despite needing an internal power source, it is possible to build an IR tag with small dimensions (20x20x5mm) that operates from coin cells and has a lifetime of 1 to 1.5 years. The Olivetti Active Badge [19] is an example of one of the first badges of this kind. There are other commercial examples of this type of badge or tag such as those sold by Versus Technology Inc www.versustech.com, and Arial Systems www.arialsystems.com.

However the real potential for ubiquitous tagging rests with the passive tag, requiring no internal power source. Active tags replicated on the scale of billons need too much maintenance and are impractical for large-scale ubiquitous use.

PARTS VS. WHOLES

Currently, tags are used primarily to identify wholes: entire runners, machine parts or cows. An interesting set of issues arises when the taggee (the thing being tagged) can either change form, or separate into parts.

At Xerox PARC, we have experimented with tagged physical documents using optical tags (e.g. glyphs or barcodes) and with RFID tags embedded in paper clips or seals [18]. When a multi-page document is separated into individual pages, does the document change identity? Or does the Platonic whole document still exist?

So the question becomes a nearly philosophical one with very practical implications: what does a tag identify? When a tag becomes sufficiently small and inexpensive, increasingly smaller objects can be tagged as components, rather than large expensive wholes. Now the expensive whole can be identified as the aggregate of the many component identities. In the case of the marathon runners, for races of the future, many personal articles (shoes, socks, watches, headbands) might be tagged and therefore rules would need to be put in place as to what 'crossing the finish line' means. Is it the first personal tag to cross the line, or only when all the personal tags have crossed for that person? A shopping cart brings up a similar issue. If individual products on sale have subcomponents that are tagged, the checkout tag readers must learn how to aggregate the tag data being read into the appropriate product description. The checkout should not charge for the components separately, or make the costly mistake of charging for them in addition.

The Taggants of explosives are the extreme end of this spectrum: each tag is in the micro-cent range, but is passive. If active electronic tags could be made equally small and inexpensively, they could be added into the pulp mix when paper is manufactured. This would allow each page of a composite document (say, a report or a book) to be identified as the unique combination of tags found in the assembly, rather than as just the unique identifier of the whole.

TAGS WITH BUILT-IN SENSING

In the near future, tags may become more than just identifiers of objects in space, but might also monitor status, history and events. Just as some boxes with fragile equipment now sport "excess G-force" tags (that turn red when the box is dropped beyond a set distance). Electronic tags might well keep a continuously updated history of sensed events over time, and at read-time, may not just transfer their unique identifier, but an entire time-stamped history of events as well.

Such a history might well encompass significant entity-altering events, such as a destructive act on the whole (a page being torn from a book). In such events, the composite identifier (i.e., the set of identifiers of each of the parts) would be changed, and this kind of change would be noted by the alteration in the signature of the whole.

Currently, one-wire interface, ibutton tags from Dallas Semiconductor [4], offer the ability to sense temperature within 0.5C, and store up to 1 million entries before uploading the data. In the not too distant future, one can imagine passive RFID tagging technology with the same capability.

For such uses, the challenges will be to manage power effectively (perhaps using environmental conditions to create power, e.g., rocking motions or thermal gradients) and to locally process data to minimize the total number of bits transmitted at read-time.

FROM TAGS TO NETWORK NODES

This suggests a trend: as tags become increasingly capable processors, and as they require less and less power, tags will shortly begin to seem less like static barcode identifiers, and more like active network nodes that are intermittently attached to the network

And as tags become increasingly able to modify their behavior at write-event time, one can begin to see tags that move on and off the network, acting as agents moving throughout the world gathering data and forwarding it to the next destination.

These intermittently connected nodes will become much more interesting over time, with more memory, sensing and processing capabilities. Such capabilities will require transaction processing and coordination between multiple tags.

A TOTALLY TAGGED WORLD: TAG USES

Since the Internet has become the world's de facto data communication network, such connectivity opens up many intriguing possibilities. Data associated with a tag can be made globally accessible with great ease. If every object contained an electronic tag, and the identity was automatically available to any Internet enabled computer, each object could conjure up its own data-set, while at the same time, locating the object to the time and place at which the read-event occurred. While there are some uses for tag readers attached to desktop systems, these capabilities become considerably more interesting for mobile appliances linked by a wireless connection to the Internet [18]. In this new world, by scanning any object with a tag reader, you might be able to determine the date and place of manufacture, the name of the manufacturer, download manuals with all the current errata, confirm proof of ownership and its ownership history. Furthermore, objects can reference more than just data. If an object can be identified uniquely by a computer, it can also invoke a service or a command. The position and associations of physical objects will now directly control the operation of the computer itself. This is an aspect of what some researchers call Augmented Reality [14, 22] or Ubiquitous Computing [21].

With the widespread adoption of a tagging standard and communication protocols, entirely new kinds of possibilities arise. Tagged objects can be located and tracked unambiguously.

Of course, this raises another issue that is essential to an effective tagging infrastructure: readers need to be available and described in ways that allow the tag-following applications to make use of the data. (For example, a tag reader probably ought to describe its location in latitude, longitude and altitude coordinates, as well as the surrounding building or installation.)

CAUTIONARY NOTE

And while tagging permits a wide array of services to be offered, and while domestic pets and livestock are easily tagged today, we feel there's a potentially dangerous slippery slope with respect to tagging people. While biometrics (e.g., fingerprints and iris scans) are becoming increasingly effective as unique identifiers, the notion of attaching a permanent recording transponder to a human leads to a wide variety of ethical dilemmas, and we recommend strongly against the practice. It is also interesting to note that in some sense the western world is already beginning to tag each person. Every cell phone contains a unique number that identifies it and its owner (or at least the person who pays the bills). As these additive mobile technologies continue to become smaller and more power efficient, it will not be long before we all have a cellphone of our own and have a permanent number assigned that stays with us for the duration of our lives.

This is an infrastructure that has both long term benefit, and the potential for abuse at the level of government and in business practices. It can even have unreasonable side effects, as it may provide information about your lifestyle – where you hang out, the type of restaurants you go to, the friends and associates you meet. Such information in the hands of an insurance agency may well influence the cost of premiums for life insurance. Clearly, tagging technologies that are directly associated with people are not desirable (at least if you cannot guarantee the security of the information it gives rise to).

THE FUTURE

The benefits of tagging materials and manufactured objects standout as an attractive improvement on how we carry out our business in the world of today. In the world of tomorrow, it may be uncommon to find an object that is not tagged. In the future, such an object might be treated with great suspicion, in the same way that an apparently antique piece of silverware, that does not show a Hallmark, is usually suspected to be of dubious origin.

ACKNOWLEDGEMENTS

We wish to thank members of the Extreme User Interface group at Xerox PARC: Ken Fishkin, Anuj Gujar and Beverly Harrison for their contributions; Tom Moran for supporting the tagging projects at PARC; and Noel Eberhard (Indala, Motorola), Gaetano Borriello (University of Washington) and Mark Weiser (in memory) for their inspiring discussion.

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