Published February 1, 2002. Distribution restricted to Sponsors until May 1, 2002.

AUTO-ID CENTER

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Smart Medicine

The Application of Auto-ID Technology to Healthcare

David L. Brock

AUTO-ID CENTER MASSACHUSETTS INSTITUTE OF TECHNOLOGY, 77 MASSACHUSETTS AVENUE, BLDG 3-449, CAMBRIDGE, MA 02139-4307, USA

ABSTRACT

The intelligent infrastructure proposed by the Auto-ID Center allows physical objects to communicate to one another, seamlessly through the Internet. Based on low-cost electronic tags, unique object identification numbers, common networking services and standardized protocols and languages, the proposed architecture has the potential to revolutionize the supply chain, logistics and inventory.

Although its first applications are focused on supply chain management, the concept of seamlessly communicating physical objects has many applications in numerous other domains. One area where the Auto-ID technology may have immediate and considerable impact is healthcare. The ability to provide continuity of care, continuous patient monitoring, shared yet secure medical records, valid and accurate medical dosages, medical equipment tracking and improved information display and communication, are some of the opportunities provided by the proposed infrastructure. In its full implementation, the Auto-ID technology has the potential to greatly reduce costs while increasing the reliability and effectiveness of human healthcare.

This paper reviews some of the basic component of the Auto-ID technology and presents potential applications and benefits to the field of healthcare.

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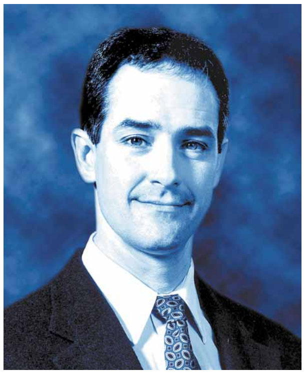
Biography



by David L. Brock
Co-Director

Dr. David Brock received Bachelors degrees in theoretical mathematics and mechanical engineering from MIT, and his Masters and Ph.D. degrees from the Department of Mechanical Engineering at MIT with an affiliation to the Artificial Intelligence Lab. He is currently a Principal Research Scientist in the Laboratory for Manufacturing and Productivity and Co-Director of the MIT Auto-ID Center. Dr. Brock is also the Founder of Brock Rogers Surgical, a manufacturer of robotic medical devices. Dr. Brock has worked with a number of organizations including the Artificial Intelligence Laboratory, the Massachusetts Eye and Ear Infirmary, DARPA, Lockheed-Martin, Loral, BBN and Draper Laboratories.

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This paper reviews some of the basic component of the Auto-ID technology and presents potential applications and benefits to the field of healthcare.

1. INTRODUCTION

The intelligent infrastructure proposed by the Auto-ID Center allows physical objects to communicate to one another, seamlessly through the Internet. Based on low-cost electronic tags, unique object identification numbers, common networking services and standardized protocols and languages, the proposed architecture has the potential to revolutionize the global supply chain, logistics and inventory.

Although its first applications are focused on supply chain management, the concept of seamlessly communicating physical objects has many applications in numerous market sectors. One sector where the Auto-ID technology will have immediate and considerable impact is healthcare. The ability to provide continuity of care, continuous patient monitoring, shared yet secure medical records, cross-checked and validated drug and radiation dosing, medical equipment tracking and improved information display and communication, are some of the opportunities provided by the proposed infrastructure. In its full implementation, the Auto-ID technology has the potential to greatly reduce costs while increasing the safety, reliability and effectiveness of healthcare.

This paper reviews some of the basic component of the Auto-ID technology and presents potential applications and benefits to the field of healthcare.

2. TECHNOLOGY AND INFRASTRUCTURE

The Auto-ID Center envisions an intelligent infrastructure that automatically and seamlessly links physical objects to the global Internet. This network will have a number of important characteristics. First, unlike conventional bar-codes, this system will network physical objects without human intervention or manipulation by automatic machines. Second, the network will be seamless. In other words, it will operate continuously throughout the environment rather than just at the checkout or exit, as with current scanning and Electronic Article Surveillance (EAS) systems.

Third, the network will be relatively inexpensive. Although it was technically possible to create such a network in the past, new technologies make its practical implementation a reality. Fourth, the network will be ubiquitous, operating in many diverse environments – from manufacturing plants and distribution centers to retail establishments and homes. Finally, the network will adopt standards in cooperation with governing bodies, such as the Uniform Code Council (UCC), the European Article Number (EAN) Association, the American National Standards Institute (ANSI) and the International Standards Organization (ISO), as well as commercial consortium and industry groups.

This intelligent infrastructure has four major components: 1. Electronic tags, 2. Electronic Product Code (EPC), 3. Physical Markup Language (PML) and 4. Object Name Service (ONS). We overview these components here and provide a more detailed description in the next section.

2.1. Electronic Tagging

Electronic tags refer to a family of technologies that transfer data wirelessly between tagged objects and electronic readers. Traditional bar codes may be considered electronic tags under this definition, since the printed bars reflect light and communicate their data to the laser scanner. Electronic Article Surveillance (EAS) labels also communicate information wirelessly, but only a single bit of data – whether or not an item has been purchased [1].

Radio Frequency Identification (RFID) tags, often used in "smart cards," have small radio antennas, which transmit information over a short range [2]. RFID technology may use both powered and non-powered means to activate the electronic tags. Powered devices use batteries to actively transmit data to more distant readers. Electronic highway toll systems are good examples of active RFID tags. Passive RFID devices typically use inductive coupling from an active reader to both power the tag and transmit the data.

Electromagnetic Identification (EMID) technology is a more broad designation for wirelessly tagging systems. Both the reader and tag use simple conductive surfaces for the antenna. Since conductive surfaces can be printed, fabrication costs are significantly reduced as compared to the inductive windings of the RFID tags. Future versions may cost a few cents, making widespread adoption practical.

Electronic tags, when coupled to a reader network, allow continuous tracking and identification of physical objects. Reader arrays have been fabricated and integrated in floor tiles, carpeting, shelf paper, cabinets and appliances. Similar to cellular phone grids, the reader network may provide seamless and continuous communication to tagged objects. In order to access and identify these objects, we need a means to uniquely name them.

2.2. Electronic Product Code

The Electronic Product Code (EPC) was conceived as a means to identify all physical objects [3]. The EPC code had to be sufficiently large to enumerate all objects, and to accommodate all current and future naming methods. It provided for industry coding standards, such as those from the Uniform Code Council (UCC) and the European Article Numbering (EAN) International. These standards include original the Uniform Product Code (UPC), as well as other numbering schemes, such as the Shipping Container Code (SCC-14) and the Serial Shipping Container Code (SSCC-18) [4–7]. The EPC was intended, as much as possible, to be universally and globally accepted. Since the EPC is used primarily to link physical objects to the network, it was designed to serve as an efficient information reference. Finally, the code is extensible, allowing future expansion in both size and design.

2.3. Physical Markup Language

The Electronic Product Code serves as a reference to information on the computer network. There are, of course, many methods for storing information "on-line." These include properitary and commercial databases, and relational databases, such as Structured Query Language (SQL) file systems. Web pages written in the HyperText Markup Language (HTML) are now one of the most common means of storing digital information. New approaches, such the eXtensible Markup Language (XML), promise a universal means for structured information.

In order to describe physical objects, we propose a new language specific for that purpose – the Physical Markup Language (PML) [8]. Rather than a new syntax, the PML will be based on the eXtensible Markup Language and include a set of schema describing common aspects of physical objects. Industry specific representations may be "plugged into" the common framework or derived from the shared data.

2.4. Object Naming Service

The Object Naming Service (ONS) is the "glue," which links the Electronic Product Code (EPC) with its associated Physical Markup Language (PML) data file. More specifically, the ONS is an automated networking service, which, when given an EPC number, returns a host address on which the corresponding PML file is located.

The ONS, currently under development, is based on the standard Domain Naming Service (DNS). When complete, the ONS will be efficient and scaleable, designed to handle the billions of transactions that are expected.

3. VISION

The vision of the Auto-ID Center – to provide direct and continual access to the identity, location and state of physical objects – has immediate application to medicine practice and healthcare in general. While the development of standard languages and protocols has both direct impact, in the description of medical products and devices, and indirect, through a general approach of common languages, real-time information, automated monitoring and global standardization.

In this section we will consider the overall themes of the Auto-ID approach and its general application and medicine and healthcare.

3.1. Item Identification and Tracking

The most obvious and immediate application of Auto-ID technology to healthcare is its direct use in the identification and tracking of medical products and devices.

From larger equipment, such as wheel chairs, gurneys, incubators and anesthesia carts; to diagnostic tools, such as portable ultrasound, endoscopes, aspirators, insufflators and defibrillators; and to small products, such as surgical instruments, medications, syringes, clothing, and dressings, automatic and real-time tracking will provide an immediate and direct increase in clinical efficiency and a corresponding reduction in cost. Even the electronic tagging and tracking of medical records, charts and films may have near-term benefit (that is until these data are converted to an electronic format).

The technology, standards, and systems developed at the Auto-ID Center, particularly the low-cost electronic tag and reader technology, product identification system and data storage, and standard communication protocol may be applied directly in healthcare facilities to provide the capability described above. Obvious initial benefits include inventory management, equipment tracking, item localization, medication monitoring and theft prevention.

However, the general approach of the Auto-ID center – creating integrated, intelligent infrastructures – may have a further-reaching and greater impact on medical practice and healthcare networks. In the remainder of this section, we will consider some of the general implications of this approach and, in the next, some specific applications and scenarios of its potential.

3.2. Continuity of Care

Medicine, as it exists today, segments care in specific domains – from the intensive care unit in a hospital to medicine chest in the home – each separate and detached from every other. In a modern hospital, for example, there are many different departments, each with varying degrees of monitoring and care, across a wide range of specialties. Within each department (dermatology, medicine, neurology, obstetrics, orthopedics, pathology, pediatrics, radiology, surgery, etc.) patient records, registration, monitoring information and display information are not generally shared or provided in a common format.

Beyond physician offices and hospitals, there are many other areas where medical care is administered. These include emergency personnel (police, fire, security and Emergency Medical Services (EMS)), their vehicles and facilities; and assisted living and nursing facilities, as well as individual homes, businesses and transport systems.

This disconnection between vital information and healthcare provider is compounded across international borders. Language barriers, standards of care, recording methods, units of measure, communications infrastructure and even time zones, all contribute to a nearly impenetrable wall between physician and patient. At best this may simply inhibit or delay treatment, and at worst, may be life threatening.

In discussions of future medical systems, there is nearly always a reference to distant medical care to remote locations and “third world” nations. Although the technology could be available, associated costs and difficulty in implementation usually make such schemes impractical. The infrastructure proposed here, however, could make such concepts realizable. The healthcare monitoring and communication systems at the remote location could simply “tap into” larger health network without any specialized equipment, languages and protocols. In other words, as opposed to a dedicated telemedicine, remote facilities could simply transmit and receive common to the proposed global healthcare system.

We envision a healthcare system, in which information from one domain is freely (with appropriate access control measures) exchangeable with every other domain. Using common languages, standards and protocols, data would be transmitted and received in known formats. Thus allowing applications, user interfaces, data management tools and archival systems to be written quickly and cost effectively without adapting to (or paying for) proprietary systems.

3.3. Patient Identification and Location

The patient is the most important person in the medical facility. All efforts are focused on his or her treatment, recover and eventual discharge. Just as the medical ID bracelet has for years provided positive identification for the patient, the proposed electronic tagging system may be used to provide accurate, automatic and real-time identification of the person under medical care. As with the Electronic Product Code, such an electronic identification system would allow all patient information essentially "follow" them wherever they may go. There would be no need, as with the current system, to manually correlate patient records with the individual.

The physician, for example, could know where the patient was at all times. Although not necessary in all circumstances, tracking patient movement, particularly for more critically monitored cases, could be helpful. More importantly, with a network interface device, such as a personal digital assistant (PDA) or bedside display, the physician would be assured the most accurate information for that patient – wherever that patient may happen to be.

From the nurse's point of view, knowing where patient is, as well as where the patient was, could be helpful in providing efficient care and treatment. If the patient were mobile, needed immediate care or just required some assistance, not having to search for and find the patient would be time saving and, for perhaps some cases, a life saving.

Finally, for the hospital administrator knowing the overall occupancy of the building, patient flow through facilities and general movement on the floors could help optimize resources and potentially cut costs. Resource limitations would become obvious and indications for future expansion or renovation would be validated.

3.4. Sensors and Telemetry

Measuring and maintaning the vital states of a patient is the first priority for the healthcare worker. From the basic 'ABC's (Airway, Breathing and Circulation) to sophisticated blood chemical analysis and three-dimensional medical imaging, measuring, understanding and recording patient data is an ongoing activity in the healthcare facility.

Some clinical states change slowly over time, such as general anatomy, tissue structures and chronic liasions. While others change more rapidly, such as glucose level, blood gas, temperature, etc. Still others change quickly such as cardiac electrical state, muscle activation and nerve conduction.

There are sensor systems for measuring many physiologically states in the human body such as heart rate, electrocardiogram (EKG), respirtation, blood oxygen saturation (SAO2), temperature, body position, muscle activity and others, as well as analytic systems for measuring states of recovered tissue and fluid samples.

What is common to all these systems in the measurement and recording of data values and associated information, such as the date and time of measurement, characteristics of the measuring device and particulars of the subject and sample.

What we propose is to standardize the communication of measured data using common formats and transmission protocols.

For rapidly changing data, this implies common telemetry. In other words, sensor systems transmit data (and associated information) in a common language. Disparate transducers will thus interoperate within a broad nework of readers without regard to the particular computation and transmission hardware. Similarly, within a single node, multiple sensors from a variety of manufactures communicate to the network using a common protocol.

For slowly changing data, that does not require real-time transmission, data communication will resemble common, batch-oriented markup language – common on the Internet today.

3.5. Medical Records

Many organizations and companies have attempted to standardize medical records in the past, but none have done so with great success nor with widespread clinical acceptance. Part of the reason may be the complexity and variety of the data. Another may be the individuality and variability of clinical care by both the institutions and physicians. Still another reason may be that standardization is typically implemented and recognized within professional medical specialities and not across the entire healthcare space [9]. Finally, there is the complex issue of privacy and security of medical histories.

Whatever the reason, the net result is that there is no simple, efficient and agreed upon method to share medical information. This is more than obvious during any visit to the clinic or trip to the emergency room. Basic health and status information is gather at every point. This problem is compounded for medical emergencies beyond the local area and further complicated across international borders. There is clearly a need for rapid access to shared medical information.

Our vision is a global standard for medical information that may be shared safely and securely whereever there is clinical need. There are many reasons to hope for such a goal and anticipate eventual success.

First, there is the shared effort and economies of scale available through the larger Auto-ID effort. In the development of standards for products including ownership, transaction, measurement, communication and data storage. These may be used identically as part of a healthcare standard.

Second, there are recognized models for the benefits of successfully adopted standards, such as the Internet and the World Wide Web. Globally accepted standards for medical information would have similar advantages for healthcare and medical practice.

Third, there is the technical capability only recently available, which includes wireless communication, network bandwidth, computation, data storage and memory. This coupled with the rapidly decreasing costs makes widespread adoption of digital standards a reality.

Finally, there is the understanding of the great health benefit and potentially saved lives with accurate and timely medical information. Whether in the home, clinic or operating room, the Auto-ID vision for healthcare is to provide information immediately, accurately and securly – independent of physical location.

3.6. The Future

Beyond the immediate benefits of shared, real-time medical information, the infrastructure we envision will enable wholly new capabilities and technologies. Since the data is transmitted in a common format, it will encourage the development of sophisticated information filtering systems. In other words, data may be read, reformatted and presented instantly and differently for the various users of the system. Furthermore, interface devices, such as personal digital assistants (PDAs), bedside or wall mounted displays, will “present” information instantly and appropriately for both the patient and the staff.

Finally, common, shared medical information may enable simulation and modeling packages to analyze the physiologic state of the patient and advise (or at least validate) various courses of treatment. Such systems exist today – warning of extreme physical condition – but future systems may be much more sophisticated, examining medical histories and assimilating numerous sensor input. In no way a replacement for human diagnosis, such a system could simply enumerate possibilities and reduce medical errors.

4. APPLICATIONS

Beyond the general themes of the previous section, here we offer a series of specific examples, or application “vignettes,” on the possible uses of this proposed technology.

4.1. Medical Device Localization

Most medical devices and monitoring systems are stored on portable carts. These carts move quickly from room to room in a hospital, but their location at any one time may not be known. Electronic tags in the monitors (and carts) and readers at the doorways would positively locate the equipment in a particular room. This should be sufficient to quickly locate and retrieve the cart without complex and expensive electronic tracking.

4.2. Medical Instrument Tracking

Many medical devices such as surgical instruments must be properly scrubbed, autoclaved and packaged between uses. Electronic tags on the instrument and tag readers on the instrument trays, in the sterilization chamber and in the storage cabinets can locate instruments and validate proper cleaning.

4.3. Monitoring Radioactive Isotopes

Tracking radioactive isotopes in a hospital is currently a major administrative and security burden for the medical staff. The radiation safety officer must monitor, control and record the location and interaction with the radioactive material at every step in the process – from storage to transport to administration to disposal. Clearly automated monitoring of these controlled materials would greatly relieve the bureaucratic complexity, as well as genuinely increasing safety and security.

4.4. Drug Validation

Assuming the patient where tagged while in the hospital, as well as the pharmaceutical, a simple drug record and validation process could be performed **automatically** to alter for possible errors. While current safeguards minimize mistakes, an automatic system (if properly administered) could provide reassurance, and eliminate rare, but costly medical error.

4.5. Anti-Counterfeiting

The Electronic Product Code used in the Auto-ID infrastructure is **unique**. In other words, there is one and only one EPC code in the entire network – ever. A counterfeiter would first have to create and then embed an electronic tag in the pharmaceutical if it were to be used within the proposed electronic network. If successful, the counterfeiter would have created a **duplicate** EPC. Duplicates would be easy to identify and multiple physical locations (and location histories) should be sufficient to identify the fake. In other words, authentic drug would move orderly from the manufacturer to distributor to retailer, etc., while the counterfeit would just "appear" at an unlikely locations. Finally, if the system we envision were fully realized, drugs not read electronically would be marked as suspect. At a minimum this system would make counterfeiting difficult and provide another tool for safe and effective drugs.

4.6. Compliance

One of the most important steps in effective medical treatment is compliance with prescribed with prescribed medical treatment. Electronic tags in the bottle and readers in the cabinet would identify the removal of the container, but would not know if the drug were actually ingested. Tags in the individual segments of a bluster pack could determine if a dosage were removed. Still further it has been suggested placing small electronic tags **in the pill** itself. While possible, safety, regulation and cost effectiveness may prohibit such a solution. A compromise, however, might be reached with small removable electronic tag "strips" on individual dosages.

4.7. Clinical Trials

Clinical trials for new therapies – whether drugs, biologics or devices – are enormously expensive. While the general application of electronically tags for drugs, as discussed in the previous section, may not be cost effective or practical, the limited application for positively determining compliance during clinical trails may very well be. Furthermore data recording, transmitting and logging may be automatic and continuous using the infrastructure we envision.

4.8. Patient and Physician Interaction

We have already discussed locating a patient within a hospital as a potential benefit; we may also consider identifying and recording patient/staff interactions. For "third party" payer systems, such as those in the United States, this interaction, or consultation time, between the physician and patient is often the determining factor in reimbursement. An automated system would eliminate errors, and provide a fair and accurate system for payment and disbursement.

4.9. Telemetry

The low-cost electronic tags currently under developed at the Auto-ID Center have the potential to not only provide identity, but also **telemetry**. In other words, tags equiped with correspondingly low-cost sensors could be adhered to the patient and provide continuous measurment of temperature, respiration, EKG, movement and pulse rate. This measurement would be transmitted wirelessly to the hospital reader network, where it could be stored or communicated to the appropriate hospital staff. Furthermore, since the tags would presumable comply with the proposed open standards, their transmission would work equally well in the hospital, clinic, emergency transport or home. Finally, at the price range we are considering for the electronic tags, these sensors would be disposable – elminiating the need for complex packaging and resterilization.

4.10. Medical Device Coordination

Medical device manufacturers generally produce complete, self-contained systems. For complex devices this typically includes a user interface (buttons, indicator lights, audible alarms and data display), processor (analog/digital filters, embedded computers and data communication systems) and sensors (transducers for heart rate, respiration, temperature, EKG, etc.). Every device manufacturer intends – and usually achieves – an efficient, ergonomic and regulatory compliant interface. The design of the interface – the configuration of the buttons, the graphics on the display and the character of the alarm are up to discretion of the manufacturer.

The effect in the clinical environment is often a cluttered and confusing array of user inputs, displays and alarms – with every device competing for the attention of the healthcare worker. Although effective in isolation, the aggregation of devices can lead to ineffective and, at times, detrimental situations. We have already considered standardizing telemetry from sensors to the network. Here we propose standardizing communication between layers of a medical device. In the limit, we would consider only a **single user interface**, **a single computer** and multiple sensors and effectors. Such as system would dramatically lower the cost of medical devices, while making their operation easier, safer and more effective.

4.11. Healthcare at Home

As we go about our daily lives, we are generating a wealth of physiological and medical data. We step on a bathroom scale that measures our weight, a urine analysis (from a presumably “smart” toilet) indicates potassium levels, our movements about the house (or on exercise equipment) provides general activity level (and energy expenditure) and the foods we consume give the caloric intake. Couple these with any number of envisioned wearable sensors and the result is a composite of specific physiologic state and general health.

Here networking is critical, since any one measurement is inconclusive, but taken together yields vital information. Aberrant readings could trigger a wearable sensor to analyze an EKG trace for heart failure, arrhythmia, ischemia or myocardial infarction. If low-level (sub-clinical) changes are observed, the system may advise (after verification by a physician) an adjustment in medication, together an (automatically) scheduled office visit.

5. CONCLUSION

The revolutionary concepts proposed by the Auto-ID Center and its implications for supply chain management, inventory and distribution are only the beginning of the potential applications. We have proposed, in this paper, some general ideas and concepts for increasing the effectiveness and lowering the cost of medicine and healthcare.

These objectives, however, can only be meet through simple and effective systems and standards. The electronic tagging system currently under development for consumer goods and the network infrastructure for supply chain management, provide a potential platform for a low-cost, globally accepted network infrastructure – and one, we believe, will be used effectively for medicine.

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