Enabling Ubiquitous Sensing with RFID

Roy Want, Intel Research

Radio frequency identification has attracted considerable press attention in recent years, and for good reasons: RFID not only replaces traditional barcode technology, it also provides additional features and removes boundaries that limited the use of previous alternatives.

Printed bar codes are typically read by a laser-based optical scanner that requires a direct line-of-sight to detect and extract information. With RFID, however, a scanner can read the encoded information even when the tag is concealed for either aesthetic or security reasons—for example, embedded in a product's casing, sewn into an item of clothing, or sandwiched between a banknote's layered paper.

The stealthy nature of RFID technology has raised concerns among privacy advocates that common products incorporating such tags could be tracked beyond the intended use of manufacturers and retail stores. For example, some fear that advertising agencies might exploit the technology for directed selling or that security agencies might use it to covertly monitor individuals.

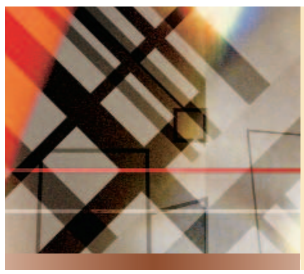
Despite the potential for misuse of invisible tracking, RFID's advantages far outweigh its disadvantages. In addition to its positive applications for retail automation, the technology can help bridge the growing gap between the digital networked world and the physical world. In the future, RFID tags will likely be used as environmental sensors on an unprecedented scale.

RFID OPERATING PRINCIPLES

RFID tags like those shown in Figure 1 are passive devices consisting of an antenna, a capacitor, and a small silicon chip encapsulated together. Recent assembly techniques allow these components to be bonded onto a resilient acrylic substrate, reducing the cost of RFID and allowing manufacturers to apply the tags to products in a form similar to a conventional label. RFID tags require no battery, and thus no maintenance; instead, they derive power from a reader using either inductive coupling or electromagnetic capture.

Once powered, the silicon chip synthesizes a digital signal to produce a modulation pattern. The tag employs either load modulation or electromagnetic backscatter at its antenna to send identity data back to the reader. The system can randomize a tag's reply time to query multiple tags simultaneously and minimize contention between their responses. Sophisticated versions of this mechanism can read all the tags in a given area within just a few reading cycles.

The energizing signal can also carry commands that write new information to flash memory inside the tag. The system can use a read command to recover this data from the tag at a later time and return the data using the same method that returns its ID. This type of memory tag, a direct result of improvements in low-power electronics, requires very little energy to operate.



In the near future, RFID tags will be widely used as environmental sensors.

An inverse square law governs energy reaching a tag from a point source; in the case of a cylindrical induction coil as a reading element, the governing law is an inverse cube. Thus, increasing the distance between a reader and tag causes a rapid reduction in available energy. Most existing commercial tags have a maximum range of about 20 centimeters, but more advanced electromagnetic capture technologies can operate at distances on the order of 3.5 meters.

EXTENDING RFID TO SENSING APPLICATIONS

The same mechanisms that an RFID reader uses to extract data from a register in an RFID tag can also be applied to collecting sensor-derived data. Extending the chip's interface capabilities to a sensor is straightforward, but the sensor design must address two engineering challenges:

- the sensor cannot use any power while the tag is not in communication with the reader, which is the usual operating state; and

- available energy is very small when the sensor is in reader range, which limits measurement techniques.

Major RFID sensing application domains include monitoring physical parameters, automatic product tamper detection, harmful agent detection, and noninvasive monitoring.

Monitoring physical parameters

Manufacturers are already deploying RFID technology in products that could spoil during transport due to temperature extremes. For example, frozen chicken has a high risk of salmonella contamination if it becomes too warm for too long. If the temperature exceeds a certain threshold, a permanent electrical change occurs in the RFID-based label shown in Figure 2. When the RFID reader interrogates the tag, it will respond with data that indicates the warning state as well as its ID.

Another useful parameter to monitor is acceleration. Fragile and sensitive products such as computers, glassware, and artwork can withstand only limited stresses before incurring damage. Today some package delivery companies monitor such items using nonelectronic dye-based tags that change color if they receive an excessive impact or vibration—for example, in a truck or while being moved in a warehouse. RFID technology could make this process more efficient and cheaper by automatically detecting an impact event without the need to manually inspect each package.

Automatic product tamper detection

Legislation requires tamper-evident retail packaging for many over-the-counter drugs, cosmetics, and other safety-critical products. Existing tamper warnings generally require a simple, single-bit interface to detect whether the sensor's normally complete physical circuit has been broken.

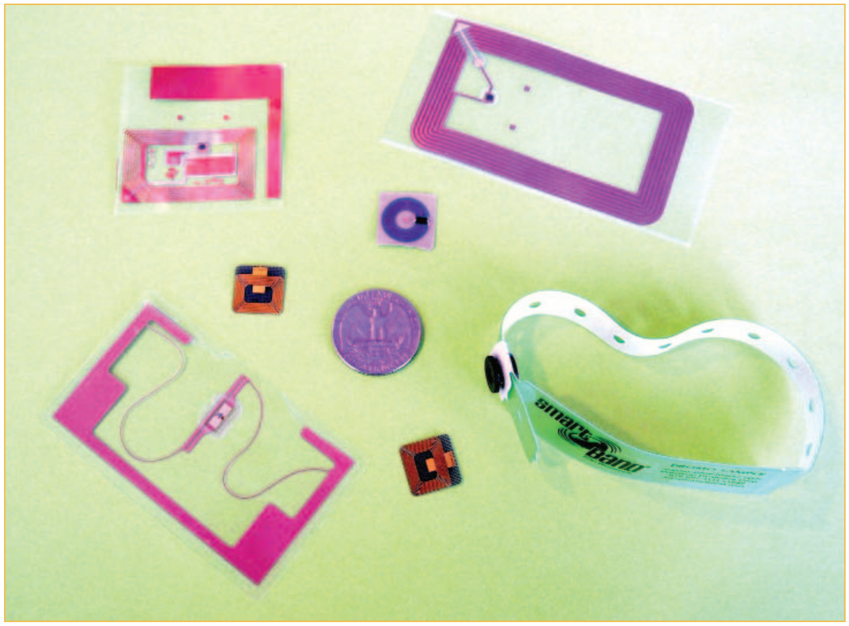


Figure 1. Commercially available radio frequency identification tags. The passive devices consist of an antenna, a capacitor, and a small silicon chip bonded together, usually on a resilient acrylic substrate.

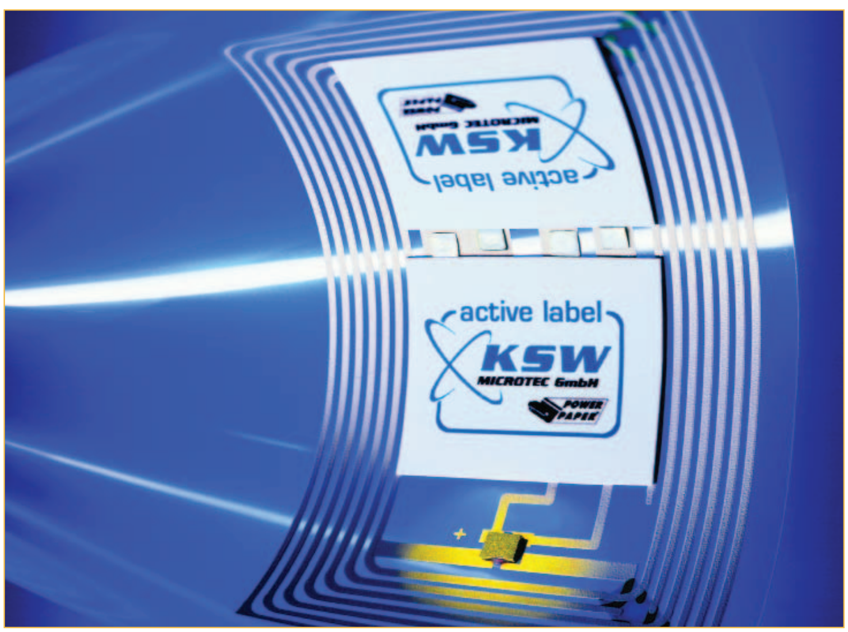


Figure 2. Temperature-threshold-monitoring RFID tag. The KSW Microtec TempSens can detect whether a food item has become too warm for too long and is no longer safe to eat. Photo courtesy of KSW Microtec.

RFID allows automatic tamper checking of multiple products from a distance, eliminating the need to directly inspect each item. The ability to monitor product integrity from factory to retail location also helps locate the source of criminal activity when tampering is detected.

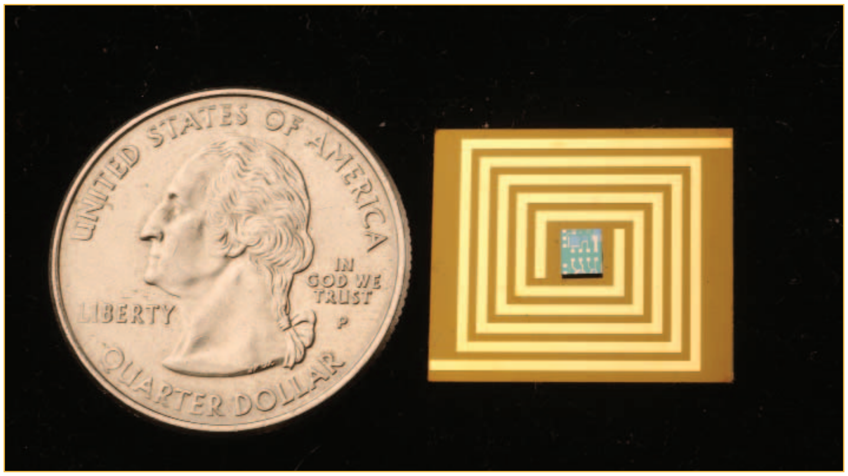


Figure 3. Bacterial sensor RFID tag. This tag is designed to provide a direct measure of bacterial contamination of food products. Photo courtesy of Auburn University.

Harmful agent detection

There is widespread concern today that terrorists might target populated areas with chemical, biological, or radioactive agents. Detectors could minimize the danger of long-term exposure to such harmful agents, many of which are invisible and odorless. In addition, deploying such devices at national ports of entry could help identify potential terrorist activity before it occurs.

Conventional harmful agent detectors are expensive and cannot be deployed on an effective scale. However, an RFID sensor utilizing simple passive-detector technology could be deployed ubiquitously. The relatively costly readers could be placed on vehicles or carried by security personnel and configured to automatically query nearby tags for telltale conditions.

At present, sensors that detect biological agents are very limited in scope; much more research is needed to develop passive detectors that are both effective and inexpensive. However, RFID could be used as the reporting mechanism to make these kinds of sensors practical.

A more mundane example of harmful agent detection is determining whether food products have been contaminated with bacteria during normal handing. Auburn University's Detection and Food Safety Center (http://audfs.eng.auburn.edu) is developing an RFID tag, shown in Figure 3, that when read will provide a direct measure of contamination due to bacterial growth.

Noninvasive monitoring

RFID also can support advanced medical monitoring. Although magnetic resonance imaging is a powerful diagnostic tool, some diseases can only be identified through direct access to the body's internal organs. New biopsy techniques and keyhole surgery offer a partial solution, but progressive medical conditions require continuous monitoring without repeated surgery. A surgeon could place an RFID sensor in a patient's body during a single procedure; later the physician could use an external reader to periodically contact the device, perhaps during routine office visits, and obtain a report on this aspect of the patient's health.

LOGGING SENSOR ACTIVITY

Knowing when and where a detected event occurred can be just as useful as what physically triggered it. Most RFID tags do not have a battery and thus cannot use an electronic clock (hybrid technologies include a small battery to accommodate additional sensors). However, readers can accurately record the time of the current reading process in the tag's electronic memory, even if it has not sensed anything of interest, thus establishing a record of reader interactions in the tag itself. Consequently, if a read event occurs at some time in the future with a positive result, the time interval for which it occurred will be known and bounded.

A reader equipped with a Global Positioning System can also write the reader's location into the tag along with the read time. If GPS is unavailable, the reader can interrogate a physically fixed reference tag at its location to initialize the reader's position before it scans any tags attached to products. In all of these variations, the tag's electronic memory becomes a distribution mechanism for its reading history, without requiring all readers to coordinate their scanning activity through an external network.

RFID sensing technology is a classic example of invisible computing in that it can operate dependably in the background, coming to the fore and signaling the need for intervention only when users need it. Although various technical and cost challenges remain, labeling commercial items with RFID tags is now becoming economically viable on a global scale.

As RFID becomes prevalent, growing economies of scale will enable the integration of environmental sensors with tags reporting on a wide range of conditions. In addition, power-rich tag readers will have access to wireless networks connected to the Internet to make the physical world readily available to Web services, taking data mining to a new dimension. ■

Roy Want is a principal engineer at Intel Research in Santa Clara, Calif. Contact him at roy.want@intel.com.

Editor: Bill Schilit, Intel Research, Seattle; bill.schilit@intel.com