MITSUBISHI ELECTRIC RESEARCH LABORATORIES
http://www.merl.com

Photosensing Wireless Tags for Assisting Geometric Procedures

Ramesh Raskar, Paul Beardsley, Paul Dietz, Jeroen van Baar

TR2005-153 September 2005

Abstract

Radio frequency tags allow objects to become self-describing, communicating their identity to a close at hand RF reader. Our goal is to build a radio frequency identity and geometry (RFIG)transponder that can also communicate geometry, inter-tag location history or context-sensitive user annotation.

Communications of the ACM

Photosensing Wireless Tags for Assisting Geometric Procedures

Ramesh Raskar, Paul Beardsley, Paul Dietz, Jeroen van Baar
Mitsubishi Electric Research Labs, Cambridge MA 02139, USA

Radio frequency tags allow objects to become self-describing, communicating their identity to a close at hand RF reader. Our goal is to build a radio frequency identity and geometry (RFIG) transponder that can also communicate geometry, inter-tag location history or context-sensitive user annotation.

Geometric Context of Wireless Tags

The geometry-rich functionality is achieved by augmenting each tag (Figure 1 top) with a photo-sensor (Figure 1 bottom). We achieve optical communication with this composite RF-photosensing tag with modulated light. In this article the operations are shown using a projector that is paired with the tag-RF-reader. The projector performs the dual operation of sending optical data to the tag (similar to your TV's IR remote control unit) and also giving visual feedback by projecting instructions on objects. Current tag-readers operate in broadcast mode with no concept of a directional communication but the RFIG tags allow locating of tags within a few millimeters, support selection of individual tags, and create a 2D or 3D coordinate frame for the tags. The system of projector and photo-sensing tag offers a set of rich geometric operations. It presents a new medium for many of the results from the area of computer vision, with projector and tags replacing camera and image interest points.

Our experimental work is based on active, battery-powered radio frequency tags. However, our goal has been to develop methods that can be used with passive, unpowered radio frequency identification (RFID) tags. The key issue in evolving our active tag system to passive tags would be power. In the work in this article, we only allowed ourselves computation and sensing consistent with the size and power levels we felt were achievable on a passive RFID system. For example, (a) tags are not photo-sensing or computing until woken up by the RF reader and (b) we do not have a light emitting diode (LED) on the tag as a visual beacon to a human or camera-based system because it would be power-hungry.

Location tracking using RF received signal strength or time of arrival is popular but requires multiple readers and the accuracy maybe insufficient for complex geometric procedures [Hightower and Borriello 2001]. Previous systems have also married RF tags with optical or ultrasound sensors to improve accuracy. Some systems use active RF tags that respond to laser pointers. The FindIT Flashlight uses a one-way interaction and an indicator light on the tag to signal that the desired object has been found [Ma and Paradiso 2002]. Other systems use a two-way interaction, where the tag responds back to the PDA using a power-hungry protocol like 802.11 or X10 [Patel and Abowd 2003]. CoolTown [The CoolTown Project 2001] uses beacons that actively transmit devices references but without the ability to point and without visual feedback. The Cricket project [Teller et al. 2003] recovers pose of a handheld device using installed RF- and ultrasound- beacons, and does projected augmentation.

How it works

Conventional tag communication works by broadcast from an RF reader, with response from all in-range tags. Limiting the communication to a required tag is traditionally achieved using a short range tag-reader and close physical placement with respect to the tag. In contrast, we can select tags for interaction at long-range using projected light, while ignoring unwanted in-range tags. The handheld device first transmits an RF broadcast. Each in-range tag is awoken by the signal, and its photo-sensor takes a reading of ambient light, to be used as a zero for subsequent illumination measurements. The projector illumination is turned on. Each tag that detects an increase in illumination sends a response to indicate that it is in the beam of the projector, and is ready for interaction.

The handheld device is aimed casually in the direction of a tagged surface. The handheld device sends an RF signal to synchronize the tags, followed by illumination with a sequence of binary patterns, i.e. binary structured light. Each projector pixel emits a unique temporal Gray-code, and thus encodes its position. The tag records the Gray-code that is incident on its photo-sensor, and then makes an RF transmission of its identity plus the recorded Gray-code back to the RF-reader. The projector uses the identity plus the recorded (x,y) location to project instructions, text or images on the tagged object. It is then straightforward to create correctly positioned augmentation on the tagged surface.

Applications

Several aspects of RFIG have been described in our previous work [Raskar et al 2004] and we have shown interaction techniques using a handheld or pocket projector [Raskar et al 2003]. The work was motivated in terms of the commercially important application of inventory control. But we believe that photo-sensing tags may have many innovative uses, and in this article our goal is to present the new ideas in the context of a few promising examples. We outline broad modes of deployment for geometric analysis. Note these are speculative uses, not work done.

(A) Location feedback e.g. warehouse management (Figure 2): Consider the task of locating boxes containing perishable items about to expire. Even with traditional RF tagging with expiry date info recorded in the indexed database, the employee would have to serially inspect boxes and mark the boxes with about-to-expire products. Using RFIG tags, the handheld or fixed projector first locates the queried tags and then illuminates them with symbols such as ‘X’ and ‘Ok’ so that the employee has a visual feedback. Note that a second user can performs similar operations, without RF collision with the first reader or the tags because the two projector beams do not overlap.

(B) Obstruction Detection, .e.g., object obstructing a railroad (Figure 3 left) A common computer vision task with camera includes detecting abnormal conditions by performing image processing. One example is detecting obstruction on railway tracks, for example raising an alarm if a person is on the tracks in a subway station or if there is some suspicious material on tracks. Processing images of videos from camera-based system to detect such events is difficult because the ambient lighting condition can change and several other activities can result in false positives. But one can solve this vision problem by instead sprinkling RFIG tags along the track. One can illuminate these tags with a fixed or steered beam of temporally modulated light (not necessarily a projector), such as 40Kz infrared beam from a sparse array of light emitters. Then the operation is similar to "beam break" technique commonly used to detect intruders. But a wireless tag based system is ideally suited for applications where running wires to both ends is impractical. Using retro-reflective markers and detecting a return beam is another common strategy to avoid wires but sprinkling a large number of markers creates an authoring nightmare. In case of RFIG, the tags id and location can be easily reported along with the status of reception of the modulated light. Lack of reception indicates obstruction which can be relayed to a central monitoring facility where a human observer can carefully observe the scene possibly with a pan-tilt-zoom surveillance camera.

(C) Ordered placement and Orientation, e.g., books in a library (Figure 3 middle):
A common task in libraries, pharmacies or for facility managers is maintaining a large number of objects in a pre-determined order. In a library, if books are RF tagged, it is easy to get a list of books within the RF range. However, without location information it is difficult to find out which books are out of alphabetically sorted order. In addition, without book orientation information, it is difficult to detect books that are placed upside down. With RFIG and a handheld projector, the system gets book title as well as location. Then the system sorts books by title as well as by their 2D geometric location. A mismatch in the two sorted lists indicates that the corresponding book is placed in a wrong position. The system known the current location for these books as well their ideal position. The projector display gives immediate visual feedback and instructions, shown in the figure as red arrows from current positions to intended position. A single book can also be tagged with two RFIG transponders, one at the top of the book spine and one at the bottom of the spine. Then comparing the coordinates of these two tags allows one to find if the book has been placed upside down.

(D) 3D Path Planning/Guiding, e.g. guiding a robot on assembly line for arbitrarily oriented objects (Figure 3 right): RFIG tags can be used in factories for robot guidance. The idea is similar to other 'laser guided' operations. Suppose a robot is instructed to grab a certain object in a pile moving on a conveyor belt. RFID can simplify the object recognition problem in machine vision but precisely locating the object will be difficult. The idea is to use a fixed projector to first locate the RFIG tagged object and then illuminate the object with a steady easily identifiable temporal pattern. A camera attached to the robot arm locks onto this pattern by doing pattern matching and allows the robot to home in on this object.

Notice that in a majority of the applications described above, the projector behaves similar to devices we are familiar with, remote controls and laser pointers, but with some spatial or temporal modulation of light. The projector is a glorified remote control communicating with a photosensor in the location-sensing phase and a glorified laser pointer in the image projection phase.

Discussion

Several problems can influence optical communication between the projector and a tag. It can be affected by ambient light. Wavelength division multiplexed communication is commonly used to solve this problem (e.g. TV remote and IR photo-sensor). The optical communication also gets noisier as projector-tag distance increases, and as the photo-sensor gets dirty. However, within these limitations, the RFIG method can support very intricate and multipurpose geometric operations with the ambient intelligence provided by wireless tags. The work indicates some of the possibilities for blurring the boundaries between the physical and digital worlds by making the everyday environment into a self-describing wireless data source, a display surface, and a medium for interaction.

References

HIGHTOWER, J., AND BORRIELLO, G. Location systems for ubiquitous computing.
Computer, 34(8):57–66, August 2001.

MA, H., AND PARADISO, J. A. 2002. The FindIT Flashlight: Responsive Tagging Based on Optically Triggered Microprocessor Wakeup. In *Ubicomp*, 160.167.

PATEL, S. N., AND ABOWD, G. D. 2003. A 2-Way Laser-Assisted Selection Scheme for Handhelds in a Physical Environment. In *Ubicomp*, 200.207.

RASKAR, R., BEARDSLEY, P.,VAN BAAR, J., WANG, Y., DIETZ, P., LEE, J., LEIGH, D. AND WILLWACHER, T. 2003. RFIG Lamps: Interacting with a Self-Describing World
via Photosensing Wireless Tags and Projectors. *ACM Trans. Graph. (SIGGRAPH) 22*, 3, 809. 818.

RASKAR, R.; VAN BAAR, J., BEARDSLEY, P., WILLWACHER, T.; RAO, S.; FORLINES, C., "iLamps: Geometrically Aware and Self-Configuring Projectors", *ACM Transactions on Graphics (TOG)*, ISSN: 0730-0301, Vol. 22, Issue 3, pp. 809-818, July 2003

TELLER, S., CHEN, J., AND BALAKRISHNAN, H. 2003. Pervasive poseaware applications and infrastructure. *IEEE Computer Graphics and Applications* (Jul).

THE COOLTOWN PROJECT, 2001. . http://www.cooltown.com/research/.

WANT, R. 2003. RFID, A Key to Automating Everything. In *ScientificAmerican*, vol. 290(1), 56.65.

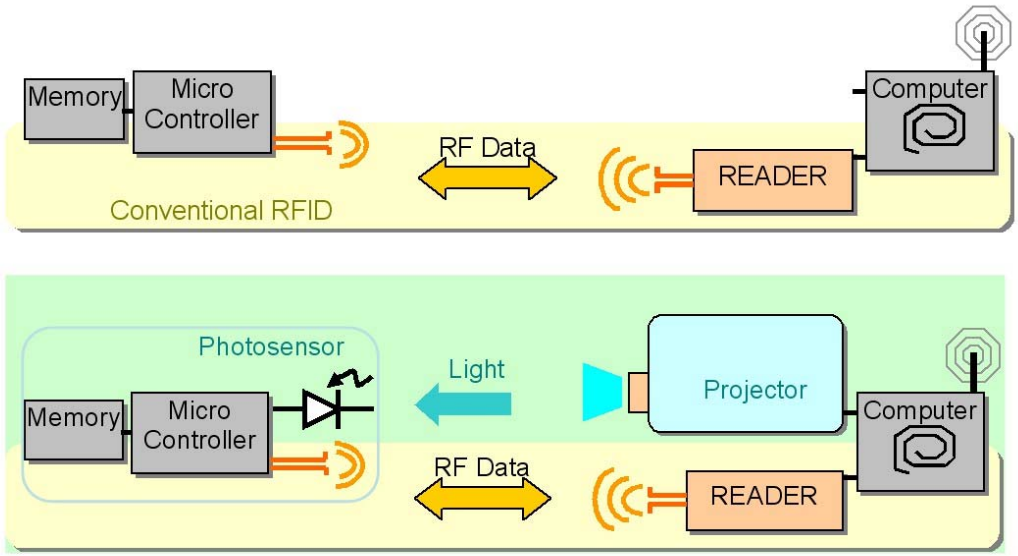

Figure 1 (Top) Conventional radio frequency identity (RFID) transponder communicates with RF reader and responds with the id number stored in the tag's memory.

(Bottom) The RFIG tag : Radio frequency identity and geometry (RFIG) transponder communicates with RF reader as well as spatio-temporal light modulator such as a modulated IR light. For example, with a full-fledged data projector, one can find the stored Id as well as the (x,y) projector pixel location that illuminates the tag.

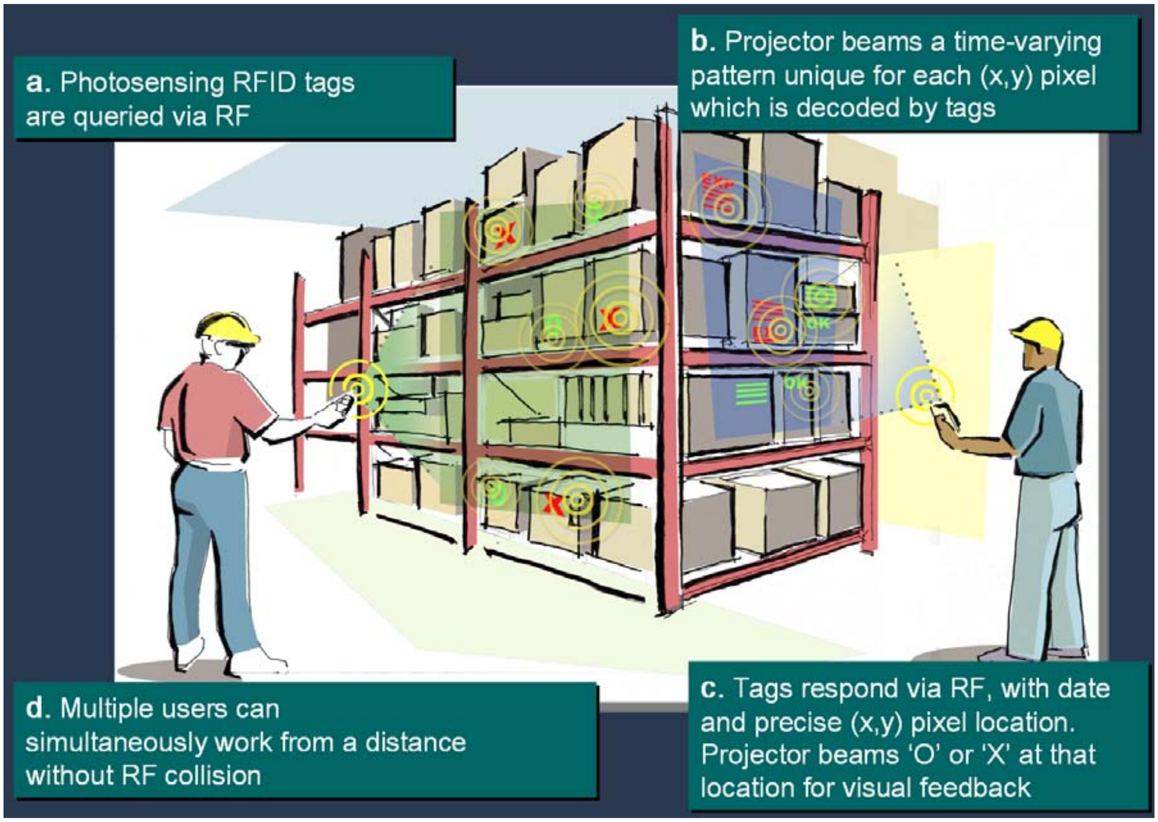

Figure 2 Application A, Warehouse Scenario: Employee locates items about to expire and gets visual feedback. A second user performs similar operations, without conflict in the interaction because the projector beams do not overlap.

Figure 3 (Left) Application B, Detecting obstruction on railway tracks, such as person on tracks near a platform, disabled vehicle at a rail-road intersection or suspicious material on tracks. Finding obstruction with a camera-based system is difficult. The idea is to sprinkle RFIG tags along the track and illuminate them with a fixed or steered beam of temporally modulated light (not necessarily a projector). Tags respond with status of reception of the modulated light. Lack of reception indicates obstruction which can be relayed to a central monitoring facility where a human observer can carefully observe the scene possibly with a pan-tilt-zoom surveillance camera.

(Middle) Application C, Books in a library. If books are RF tagged, it is easy to get a list of books within the RF range. However, without location information it is difficult to find out which books are out of alphabetically sorted order. In addition, without book orientation information, it is difficult to detect books that are placed upside down. With RFIG and a handheld projector, the system gets book title as well as location. Based on the mismatch in title sort with respect to the location sort, the system gives immediate visual feedback and instructions, shows here as red arrows for original positions.

(Right) Application D, 'Laser' guided robot: To guide a robot to pick a certain object in a pile moving on a conveyor belt, the projector locates the RFIG tagged object and illuminates it with easily identifiable temporal pattern. A camera attached to the robot arm locks onto this pattern and allows the robot to home in on this object.