# Arfid: A Reconfigurable Fabric of Input Devices for the Internet of Things

**James Youngquist**
University of Washington
Seattle, WA 98195 USA
jay@cs.uw.edu

**Joshua R. Smith**
University of Washington
Seattle, WA 98195 USA
jrs@cs.uw.edu

**Aaron Parks**
University of Washington
Seattle, WA 98195 USA
anparks@uw.edu

**Benjamin Ransford**
University of Washington
Seattle, WA 98195 USA
ransford@cs.uw.edu


*UbiComp '14* Adjunct, September 13–17, 2014, Seattle, WA, USA
ACM 978-1-4503-3047-3/14/09.
http://dx.doi.org/10.1145/2638728.2638789

## Abstract
Low-cost, easily deployable, reconfigurable, movable input devices can enable adaptive workflows in commercial, industrial, and home environments. A key limitation of previous reconfigurable control systems is their high cost or maintenance burden (e.g., battery changes or wiring setup). Our poster presents Arfid, a "fabric" for reconfigurable input devices that connects low-cost, battery-free inputs to arbitrarily specified functions in their surroundings via a buildingwide network of RFID readers. Users can reassign controllers' functions using a simple web interface.

## Author Keywords
Wireless Power; RFID; Tactile Inputs

## ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous.

## General Terms
Ubiquitous Computing

## Overview
To realize an environment replete with unobtrusive computers performing helpful tasks, it is crucial to present user interfaces that require no training. The computers

themselves should be inexpensive, low-maintenance machines that are concealed to the maximum extent possible.

Past work on energy-harvesting computers powered by radio waves (e.g., the WISP [6, 8]) allowed sensing and computation to be deeply embedded where batteries and wired power would be impractical. New platforms use diverse sources of radio energy such as television or cellular signals [5], and a trend toward increasing energy efficiency is expanding the variety of workloads that can run on these devices [2]. We consider a world in which some amount of wireless power is available to any device that wants to harvest it, and ask the question: what kinds of human interactions would ubiquitous power enable?

Our poster presents *Arfid* (A Reconfigurable Fabric of Input Devices). Arfid places lightweight battery-free input devices (*Arfid controllers*) based on the WISP in an environment in which wireless power is plentiful thanks to a buildingwide deployment of RFID readers [10]. A middleware layer supervises the operations of the RFID readers, collects inputs from Arfid controllers throughout the building, and performs actuation tasks. By interacting with simple tactile inputs on the controllers, users can control arbitrary functions mediated by the middleware. A simple out-of-band mechanism allows users to dynamically reassign controller functions. For example, a dial and button control placed in a conference room can control the lights at the beginning of a meeting, then be reassigned during the meeting to control the volume of a teleconferencing unit. The same physical device could also be used as a trackable roving call-for-assistance unit, or could even detect events in the environment such as doors opening and closing.

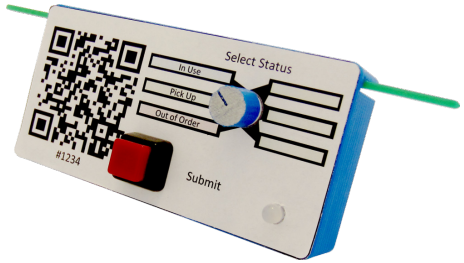


**Figure 1:** An RF-powered Arfid prototype controller supporting pushbutton and rotary-dial input modalities. Users scan the QR code to configure, via a web interface, the function that the tactile input controls for each individual device.

The novel contribution of Arfid is incorporating battery-free computation platforms, such as WISP, as general-purpose input devices in a flexible middleware and actuation framework. Users are presented with battery- and maintenance-free tactile interfaces. Arfid is a first exploration into battery-free controller distribution throughout an environment with ubiquitous wireless power. Arfid enables instantly reconfigurable applications in commercial, industrial, and residential settings.

## Motivation

Most input devices meant to control physical objects are simple; they need only be capable of reporting or actuating a small number of states or a single continuous value. For example, a conventional lightswitch has two possible states; a dimming lightswitch can be a knob or slider whose states are confined to a specific range. People already know how to interact with these inputs; they need not understand anything about what happens between the input device and the actuated system. Tactile controls are already spread throughout the built environment, so people are accustomed to physically distributed inputs and separation of inputs and actuation.

We therefore chose to implement Arfid controllers that combine familiar tactile inputs with invisible wireless connectivity to centralized actuators.

## Implementation: Battery-Free Input Devices

Arfid controllers are based on the WISP [6], an open-source battery-free computing platform that harvests radio frequency (RF) energy from RFID readers. We developed a modified version of the WISP that upgrades its microcontroller, firmware, and harvesting circuitry to dramatically extend the read range from approximately 3 m to approximately 10 m—well within the range of the RFID readers in our buildingwide deployment. We added two simple tactile controllers via the onboard microcontroller's input pins: a pushbutton and a rotary dial. Arfid controllers also inherit the WISP's accelerometer and temperature sensor. Other tactile inputs and sensors are easily connected via pins.

When queried by an RFID reader, the controller's firmware collects the present state of the tactile inputs and encodes it into a standard RFID protocol message that it backscatters (reflects) to the querying reader along with the controller's unique numeric identifier. The reader informs the middleware that it detected a controller, and the middleware dispatches an appropriate actuation event.

Each Arfid controller bears a QR code, a two-dimensional barcode that she can scan with a smartphone or laptop. Scanning the QR code brings up a controller-specific webpage that presents possible actuation functions that match the controller's available inputs and location—e.g., state-toggling functions or continuous adjustments. Users can receive feedback via text message or email.

In our Arfid prototype, the limitations of RFID read range require an investment in a multiple-reader infrastructure. However, the distribution of readers also allows controllers to be located to within 10 m, enabling location-aware applications. A second challenge of intermittent RF power that our prototype does *not* address is indicating to users that their inputs were received and the actuation successful.

## Buildingwide Deployment

We tested Arfid in our building, a multi-story enclosed environment with an internal network of 36 RFID readers [10]. The readers' antennas are spaced roughly 10 feet apart in the building's hallways. Each reader has two to four antennas attached, for a total of 133 antennas available to power (and communicate with) Arfid tags throughout the building. (The poster will plot the results of our evaluation to demonstrate that Arfid tags are usable throughout the environment.)

We envision Arfid controllers attached to walls or tables in shared, multi-use facilities like our academic office building. However, since they lack batteries or wired power, controllers can also be made portable (e.g., a thermostat that controls the temperature in whatever room the user enters) or sealed within other objects (e.g., outdoor fixtures).

## Related Work

Phidgets [3] and VoodooIO [4] envision physical user-interface "widgets" for conventional computers that represent familiar onscreen concepts. Arfid, in contrast, is meant to enable interactions with physical components that are computer-controlled but are not themselves computer hardware or software.

Arfid shares its motivation with the recent work of Simon et al., who add input controls to passive (conventional)

RFID tags and modify the physical-layer behavior of RFID to encode controller inputs [7]. Their technique builds on the work of Avrahami et al. and Thomas et al., who integrated on–off switches with RFID tags [1, 9]. These approaches yield high-resolution tactile controls that can be integrated with physical components, much like Arfid controllers. Their use of conventional passive RFID tags allows them potentially greater range than Arfid controllers. However, the key advantage of Arfid controllers is that they work with widely deployed off-the-shelf RFID readers and are individually programmable, enabling rich applications that are unfeasible with conventional (ASIC-based) RFID tags.

## Acknowledgements

We thank the reviewers for their feedback. This work was funded in part by the Intel Science and Technology Center for Pervasive Computing, a Google Faculty Research Award, and NSF award number CNS-1305072.

## References

[1] Avrahami, D., and Hudson, S. E. Forming interactivity: A tool for rapid prototyping of physical interactive products. In *Proc. 4th Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques (DIS)* (June 2002).

[2] Gollakota, S., Reynolds, M., Smith, J., and Wetherall, D. The emergence of RF-powered computing. *IEEE Computer 47*, 1 (Jan. 2014).

[3] Greenberg, S., and Fitchett, C. Phidgets. In *14th Annual ACM Symposium on User Interface Software and Technology (UIST) Video Proceedings* (Nov. 2001).

[4] Laerhoven, K. V., Schmidt, A., and Gellersen, H.-W. Pin&Play: Networking objects through pins. In *Proc. 4th International Conference on Ubiquitous Computing (UbiComp)* (Sept. 2002).

[5] Liu, V., Parks, A., Talla, V., Gollakota, S., Wetherall, D., and Smith, J. R. Ambient backscatter: Wireless communication out of thin air. *ACM SIGCOMM Comput. Commun. Rev. 43*, 4 (Aug. 2013).

[6] Sample, A. P., Yeager, D. J., Powledge, P. S., Mamishev, A. V., and Smith, J. R. Design of an RFID-based battery-free programmable sensing platform. *IEEE Transactions on Instrumentation and Measurement 57*, 11 (Nov. 2008).

[7] Simon, T. M., Thomas, B. H., Smith, R. T., and Smith, M. Adding input controls and sensors to RFID tags to support dynamic tangible user interfaces. In *Proc. 8th International Conference on Tangible, Embedded and Embodied Interaction (TEI)* (Feb. 2013).

[8] Smith, J. R., Sample, A. P., Powledge, P. S., Roy, S., and Mamishev, A. A wirelessly-powered platform for sensing and computation. In *Proc. 8th International Conference on Ubiquitous Computing (UbiComp)* (Sept. 2006).

[9] Thomas, B. H., Smith, M. T., Simon, T., Park, J., Park, J., Von Itzstein, G. S., and Smith, R. T. Glove-based sensor support for dynamic tangible buttons in spatial augmented reality design environments. In *Proc. 15th IEEE Intl. Symposium on Wearable Computers (ISWC)* (June 2011).

[10] Welbourne, E., Koscher, K., Soroush, E., Balazinska, M., and Borriello, G. Longitudinal study of a building-scale RFID ecosystem. In *Proc. 7th Annual International Conference on Mobile Systems, Applications, and Services (MobiSys)* (June 2009).