Low-Cost Physical Shopping Cart Content Tracking

A novel approach using multiple RFID bands and battery-free technology

EE 498/598 SP18 • Sponsor *Xinova* • **Students** *Alvin Cao, Attila Herrera, Hung Tan Huynh* • **Faculty Adviser** *Prof. John Sahr* • **Industry Mentors** *Shivani Ludwig, Jake Russell*

International Patent Application Number PCT/US2017/17071 Pending

1 • Motivation

Offer brick-and-mortar retailers a similar level of consumer analytics afforded by online shopping

Traditional retailers are limited to a single stream of data at checkout. There is a strong interest in access to more real-time metrics, including:

- **Order of Purchase:** know in what order items were added
- **Real-Time Tracking:** know exactly when items are added or removed
- **Location Tracking:** know where carts are in the store at all times

These metrics can be translated into useful analytics for retailers to improve customer experience, loss prevention, and market research capabilities.

2 • Our Approach

We propose a cart-mounted system using HF-to-UHF frequency 'translation' emphasizing low cost, low power, and easy installation while accepting constraints on throughput

Systems for real-time consumer analytics in brick-and-mortar stores do already exist, but we propose a novel approach to improve upon their most limiting factors. Like many other approaches, we require that **each item in a store must have a RFID tag**, but items sharing the same Electronic Product Code (EPC) may share the same RFID Unique Identifier (UID). We reference the following RFID bands in our system and compare our approach with major existing ones:

Relevant RFID Frequency Bands

**Passive (unpowered) tag read range*

Frequency	Designation	Read Range*	Typical Use
13.56 MHz	High Frequency (HF)	up to 1m	Entry systems
902-928 MHz	Ultra-High Frequency (UHF)	up to 12m	Inventory tracking

Comparison with Existing Systems

	Amazon Go	UHF RFID cart	Our System
Primary Tech	Computer Vision	UHF RFID	HF and UHF RFID
Deployment	Requires overhaul	Installable	Easily Installable
Cost	Likely High	High	Low
Power Usage	N/A	High	Low
Throughput	High	High	Limited

Primary System Features

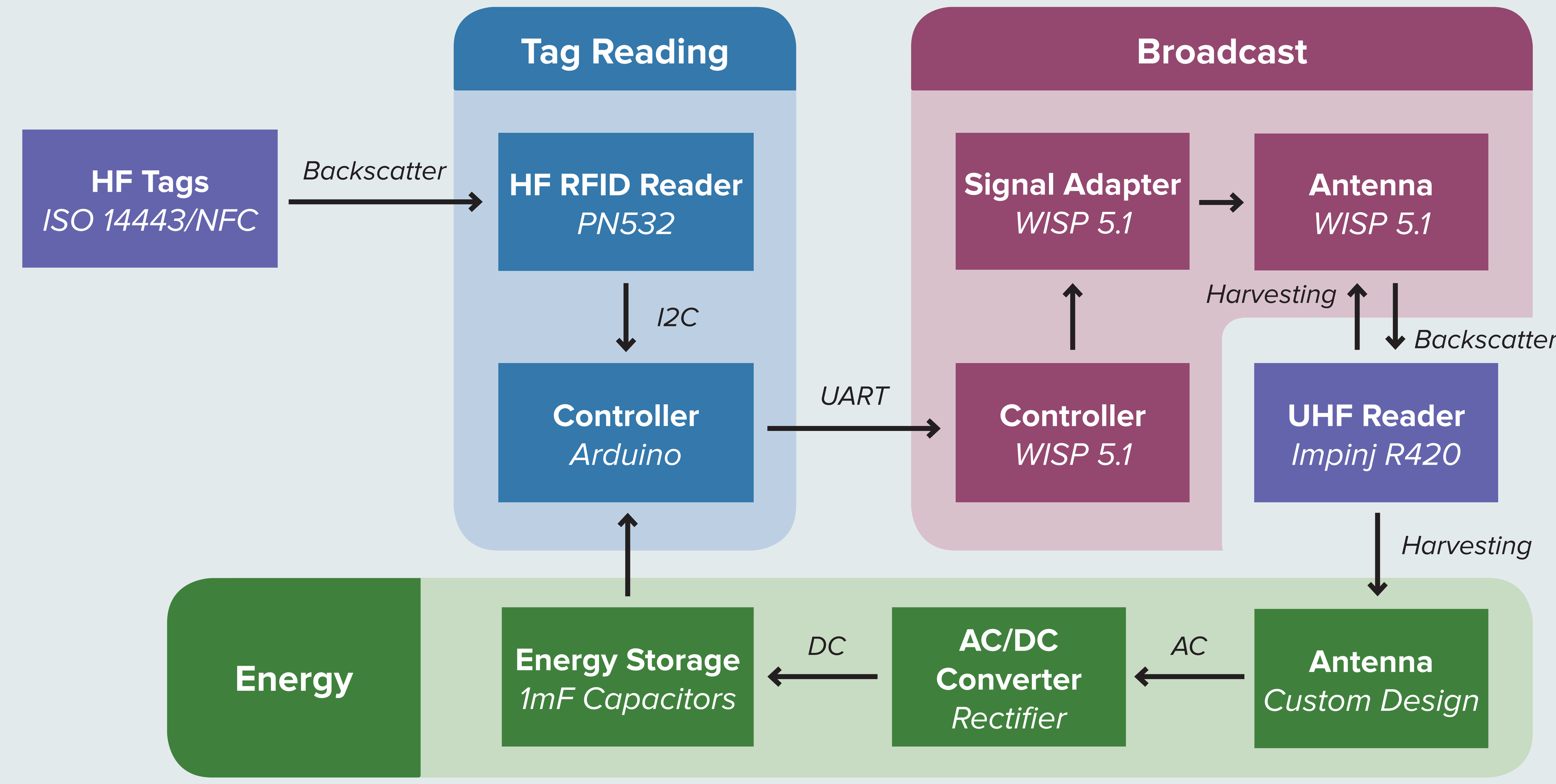
- **Products are HF-tagged:** we read HF-tagged rather than UHF-tagged products
- **Endpoint is still UHF:** we use industry standard UHF readers for data collection
- **Battery-free:** our device ideally functions using only harvested power

Tech Stack: C (MSP430), Arduino, WISP 5.1, Python, sllurp

3 • System Architecture

Our **system architecture** consists of 3 subsystems:

- **Tag Reading**, which reads HF tags within the cart and packs the data to send to Broadcast
- **Broadcast**, which encodes the HF tag data in a UHF backscatter signal, battery-free
- **Energy**, which provides power to the Tag Reading subsystem using passive harvesting

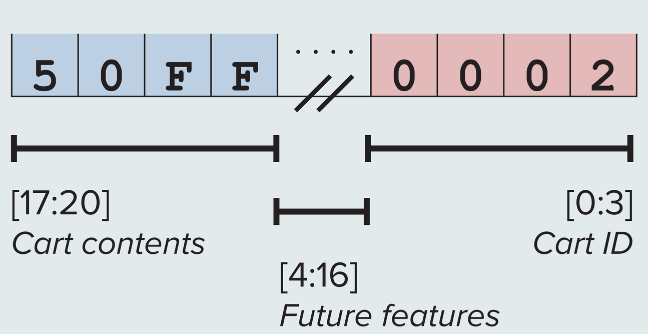


Tag Reading

HF-tagged products (*ISO 14443, aka NFC*) are first read by a HF RFID reader. Our current implementation uses an Arduino Uno with a PN532 reader shield. To encode the contents of a cart in a single UHF tag UID (20 Hex digits) readable by the endpoint, we use a lookup table to pack data representing the cart contents into the first 4 digits, supporting 65536 unique items. The last 4 digits are used as the cart ID number. The remaining 12 digits are reserved for future features, such as a count of multiple copies of the same item.

HF to UHF Tag Encoding Scheme

All fields in hex



Broadcast

WISP 5.1

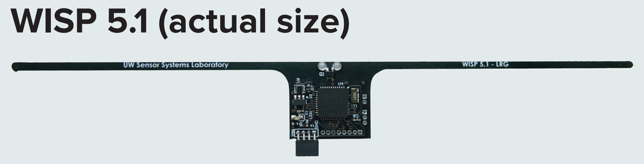
The crux of our HF-UHF frequency translation capability is the open-source **Wireless Identification and Sensing Platform** (WISP 5.1) in development at the UW Sensor Systems Laboratory. It allows us to perform battery-free forwarding of data provided by the Tag Reading subsystem into the WISP's UID, which is then read like a normal UHF tag by the endpoint reader.

Although the WISP includes onboard UHF energy harvesting via its built-in antenna, we place its microcontroller (MSP430 with FRAM) in sleep mode most of the time, waking it only when it receives new data from the Tag Reading subsystem, which we limit to 1 update per 5 seconds (0.2 Hz).

Endpoint

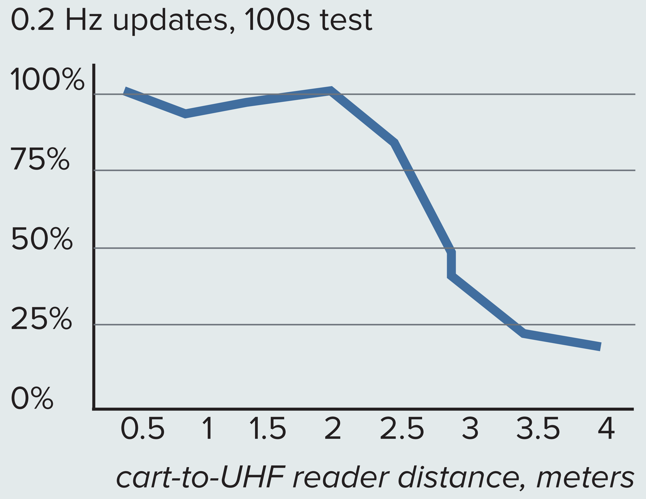
Our endpoint is an industry-standard Impinj R420 UHF RFID reader with a right-hand circularly polarized (RHCP) antenna at 32.5 dBm (1.78 W).

WISP 5.1 (actual size)



Read Throughput vs Range

0.2 Hz updates, 100s test



Energy

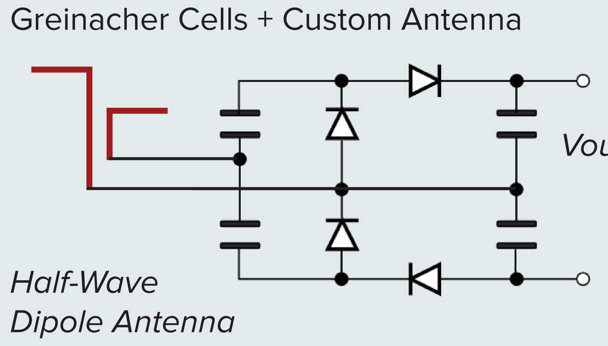
In an attempt to provide power for the Tag Reading subsystem, oppositely polarized Greinacher cells act as a voltage quadrupler along with a custom-built dipole antenna to harvest the UHF reader signal, designed as follows:

Antenna Length = $\lambda/2$ = (c/902 MHz) /2 = 16.5 cm

We obtain a DC voltage output of 2-4 V with small maximum current draw. Unfortunately, this is still unable to sufficiently power our Tag Reading subsystem, so we use an onboard battery as a functional replacement.

UHF Energy Harvesting Circuit

Greinacher Cells + Custom Antenna



4 • Evaluation

Our results successfully demonstrate a proof-of-concept of the proposed system but reveal critical performance tradeoffs. Any future development should aim to mitigate these factors.

Strengths

Cost	Despite the WISP not being mass-produced, the cost of our system (~$200) is still about **one-tenth the cost** of UHF-based cart devices.
Deployment	Our system **can be retrofitted onto carts** and installation of UHF reader endpoints **do not require any special hardware**.
Power Usage	Our system uses **significantly less power** than UHF-based cart devices.

Limitations

Range	Our system is notably **constrained on both HF and UHF read ranges** (approximately 10cm HF read range, 4m UHF read range).
Passivity	We are currently **unable to power the HF reader using RF energy harvesting** alone and rely on an onboard battery instead.
Robustness	Our device **does not work with metallic objects** (ie. cans or metal carts). Our device is dependent on open-source university research hardware.
Throughput	We see a logarithmic **decay in read throughput with increasing range**.

Future Work

The focus of our project was to demonstrate the feasibility of a HF-to-UHF frequency 'translation' architecture for tracking cart contents. While we believe the architecture is demonstrably promising, significant additional work is required for it to be robust in practice.

Performance

- Replace Tag Reading subsystem controller with low-power microcontroller
- Explore different HF RFID standards (ie. *ISO 15693*) to increase HF read range
- Use larger or multiple HF antennas on a single cart for better multi-item detection
- Optimize RF energy harvesting antenna and charge circuit

Additional Features

- Explore in-store layout of UHF readers to enable location tracking of carts
- Optimize characteristics of UHF reader ie. directionality, power, etc.
- Support counting of multiple copies of the same item in the cart

5 • Acknowledgements

In addition to our wonderful faculty and industry mentors, we would also like to extend our thanks to the following people who greatly assisted us throughout the project:

Xingyi Chen • Vaishnavi Ranganathan **Zerina Kapetanovic • Saman Naderiparizi** *Sensor Systems Laboratory*	For lending us WISP 5.1 hardware and supporting us in the development process
Lefteris Kampianakis *Sensing Computing Communications Group*	For advice in the early stages of our project
The Impinj Capstone Team	For lending us equipment
Shruti Misra	For being a responsive, supportive TA

About Xinova

Headquarted in Seattle, Xinova helps organizations develop opportunities for innovation by connecting them to a curated network of 10,000+ inventors. Xinova's clients range from startups to multinational corporations.