Perpetual Smart Signage using Ambient Energy Harvesting

[Demo Abstract]

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ABSTRACT

Power is a key constraint in the implementation of pervasive displays. This work takes the approach of eliminating batteries on a display platform through the combination of two trending technologies: Bistable electrophoretic displays, and ambient radio energy harvesting. An electrophoretic (E-ink, E-paper) display is used as part of a sensing, computation, and communication platform. The platform takes advantage of the non-volatile nature of electrophoretic displays to enable extremely low power operation, making possible the use of ambient radio frequency energy as a power source to enable battery-free operation and long lifetime. A local user interface, onboard physical sensors, and radio link allow for exciting applications which all require no battery replacement or maintenance.

1. INTRODUCTION

Electrophoretic bistable displays, popularly known by the trade names E-ink and E-paper, are an exciting enabling technology for ultra low power pervasive displays. The unique quality which makes them ideal for low power applications is their bistability, or ability to retain state with zero power consumption; only the changing of the displayed image requires power. Slowly-varying data, such as weather indicators, calendars, and bus schedules, can thus be represented at very low power cost.

A fitting method for powering such a display platform is through the use of ambient radio frequency (RF) energy harvesting. In this work, a platform resembling a wireless sensor node or mote and including a display and minimal user interface is powered exclusively from scavenged energy found in near-ubiquitous signals such as television broadcasts, mobile/cellular signaling, and WiFi transmissions. Prior work has shown that ambient RF harvesting can be used to power off-the-shelf weather stations with LCD displays, thus demonstrating a proof-of-concept for ambient-powered displays[1, 3], but these systems are inherently limited by the constant power requirements of the LCD. A bistable display platform's RF power requirements can be reduced to zero if needed without loss of the image, and the energy required to update the image can be collected as slowly or quickly as needed based on the amount of power available from the RF source(s).

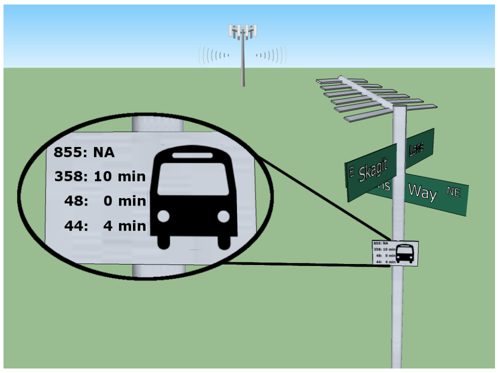

Figure 1: An ambient RF harvesting, wirelessly-updatable display could be used in a dynamically updated transit schedule

Prior work has demonstrated the sensing, computation, and communication capability of an ambient RF-powered platform [2], which enable the motivating example applications described here. One sample application is the use of this display platform as a wirelessly-updatable public transit info panel, as illustrated in Figure 1. Another sample application, detailed in Figure 2, uses onboard sensing and computation to generate and display a weather forecast.

2. DISPLAY DESIGN

Electrophoretic displays consist of millions of tiny microcapsule pixels containing oppositely charged white and black particles suspended in a clear fluid. When a voltage is applied across the capsule, the charged particles move to either the top or bottom resulting in a light or dark bistable pixel that will continue to hold its state without power. Segmented displays contain electrodes of the desired shape and a top plane, and are updated by applying a differing voltage to the top plane and the desired segments. Previous generations of the technology required high voltages to operate, but E-Ink's recent line of customizable 5V segmented displays allows use of arbitrary shapes in much lower power applications.

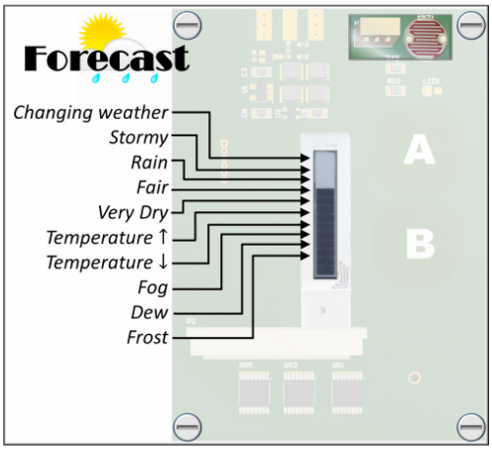

Figure 2: Onboard sensing and computation enables local weather forecasting.

Our display is programmed via a custom driver circuit consisting of a deserializer connected to a microcontroller via SPI (serial peripheral interface). This allows arbitrary bit patterns to be formed on the display electrodes for independent control of each display segment. While the microcontroller operates at 1.8V to conserve power, the E-ink segmented displays require 5V to update. Thus, a boost converter was used to provide a 5V supply while updating the display. The display driver circuit may be completely de-energized in between updates to conserve power; due to the bistable nature of the electrophoretic display, the image will be maintained. In our tests, the entire display update procedure used less than 200 μJ of energy, and this number can be further reduced by hardware and firmware optimizations. For instance, selective updating of one segment can use less energy than a global update of the entire display.

3. SENSING, COMPUTATION, AND COMMUNICATION

The MSP430 series of microcontrollers from Texas Instruments are well known for their advantages in low power design, such as low sleep current, fast startup time, and energy savvy peripherals. In the current prototype of the system, a CC430F5137 (MSP430 with integrated 915MHz radio transceiver) handles the computation and communication aspects of the system, and manages sensing and display update operations.

To implement a demonstration of the weather forecasting application, onboard temperature, humidity, atmospheric pressure, and luminosity sensors have been added. Each of these sensors was carefully selected for its low power requirements, and each can be power-gated in order to reduce the operating power requirements of the platform and allow for power management schemes to be implemented. Additionally, a set of user inputs in the form of touch sensing buttons were added, and can be used to demonstrate an interactive display.

4. RF HARVESTING CONSIDERATIONS

The ambient RF signals targeted by this RF harvesting platform are in the UHF band, which spans from 300 MHz to 3 GHz. This band was targeted because of its popularity in wireless broadcast and communication systems, and the resulting high density of available ambient power sources. Most broadcast television transmitters, cellular base transceiver stations, and WiFi access points make use of the UHF band.

There are many options, and many variables to sift through in selecting an antenna for such an application. Specifically, an optimal polar pattern, gain, and bandwidth should be chosen. In our prototype, both low gain (less directional) dipole, and high-gain (highly directional) Yagi-Uda antennas will be tested.

The RF harvesting section of the system consists of a rectifier, low voltage DC-DC charge pump, and a charge storage reservoir in the form of a small capacitor. The sensitivity of the harvester designed is around -18 dBm (15.8 μW), which translates to a projected operating radius of over 25 km around a 1 MW TV transmitter using a 6 dBi antenna. Successful tests have been performed at a distance of 10.4 km.

While the RF harvester used boasts a large range of operation, it has a downside in that it targets only a relatively narrow ($<$20 MHz) subset of the UHF band, and must be manually re-tuned to match the available channel(s) in a particular area. For widescale adoption of this system, it is imperative that the harvesting platform be able to draw power from any available UHF channel without the need to manually adjust the tuning. Planned future work will explore the options related to wideband harvesting (harvesting a larger fraction of the UHF band) and frequency-agile harvesting (a self-tuning adaptive harvester), which both have the potential to make the system more versatile.

5. CONCLUSION

This work addresses the important constraint of power in a pervasive display application by demonstrating a battery-free, ambient RF harvesting, electrophoretic display with onboard sensing, computation, and communication capabilities.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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