Unobtrusively Capturing Face to Face Interactions

William Huang, Prabal Dutta
Electrical Engineering and Computer Science Department
University of Michigan
Ann Arbor, MI 48109
{wwhuang, prabal}@umich.edu

ABSTRACT

Capturing the spatial and temporal parameters of human interactions allows for better informed disease transmission models. Smart badge type solutions have attempted to capture these parameters, but their real world deployability is minimal. The key problem stems from the unpredictability of mobile neighbors, which makes neighbor synchronization difficult, resulting in either bulky, high powered nodes or infrastructure heavy systems. To bypass this problem we designed an ultra low power ultrasonic wake up and ranging sensor, which can be kept on without significantly affecting battery life. This allows nodes to asynchronously wake up neighboring nodes, eliminating the need for infrastructure nodes and bulky batteries, and enabling the creation of easily deployable sensor networks to capture human interactions.

1. INTRODUCTION

It is estimated that the flu season results in an average annual loss of 610,660 life-years lost and $87.1 billion in total economic impact for the United States [3].

Models for aerosol transmissions, or droplets expelled during coughing or breathing, are used to better understand influenza outbreaks. These models are quite sensitive to physical human interaction parameters, such as the distance and duration of human interactions.

Surveys are the most common approach for discerning these human interaction parameters for epidemiological models [2, 5]. However, surveys depend on subjective, self-reported data, are coarse grained, and scale poorly. More objective smartphone and sensor based techniques have been explored, but they suffer from a variety of data fidelity and/or deployability problems [6, 1, 4].

Time difference of arrival (TDoA) schemes have come the closest to solving this problem by providing high ranging resolution and ensuring people are actually facing each other. TDoA transmits two signals with different propagation speeds, such as RF and ultrasonic, with the receiver calculating the distance based on the difference in arrival time of the two signals. Traditionally, TDoA systems have been difficult to deploy due to the aforementioned synchronization problem, which has led to infrastructure heavy systems.

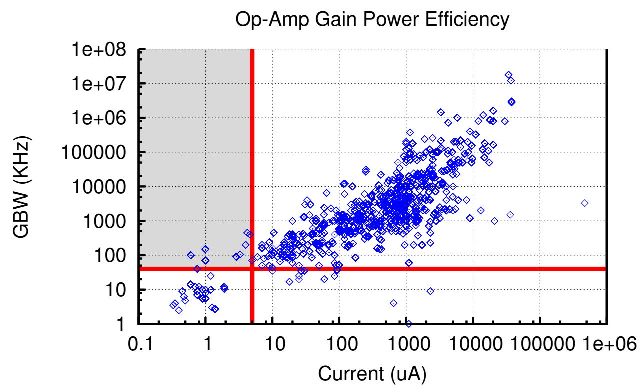

Figure 1: Analysis of current vs op amp gain. The shaded gray region highlights op amps with sufficiently high gain and sufficiently low current.

Building upon traditional TDoA systems, we have designed a small, ultra low power wearable sensor that can capture the spatial and temporal aspects of human interactions with zero infrastructure nodes. We achieve high ranging resolution using TDoA, and can transmit frequently to achieve high temporal fidelity. The key to enabling an infrastructure free system is a 16 uA ultrasonic wakeup radio built from commercially available components, which can be utilized as an always on receiver without significantly affecting battery life, solving the synchronization problem.

2. ARCHITECTURE

2.1 Circuitry

The crux of our ultrasonic wake up circuit is a receive circuitry which operates at 16 uA when no neighboring nodes are present. It does so by amplifying and digitizing incoming ultrasonic signals, allowing the circuit to generate clean wake up interrupts to an MCU.

To analyze the viability of an always on, ultra low power ultrasonic receiver, we examined 11,000 op amps from the DigiKey database which would run off a typical sensor mote power supply. The results of this analysis are summarized in Figure 1. We found two op amps which provide adequate stable amplification for 40 kHz transducers at a low enough power to be always on: the MIC861 and MIC863.

We use three $10x$ gain op amp stages, a 900 nA comparator, and an integrator circuit, resulting in a power efficient, noise resistant, and digitized receive circuit. At minimum, the transmit circuitry only requires a PWM module from the MCU.

2.2 The Protocol

Nodes can dynamically choose to be a transmitter or receiver, with an upper software layer controlling this process.

2.2.1 The Transmit Protocol

First, an ultrasonic pulse is sent, waking up and synchronizing neighboring nodes to the transmitter. Next, a radio packet and ultrasonic pulse are simultaneously transmitted, which neighboring nodes use to calculate pairwise distances.

2.2.2 Receive Protocol

Upon hearing an ultrasonic pulse, the receive circuitry generates a wake up interrupt. The software layer then disables ultrasonic interrupts and turns on the radio.

The receiver then waits for the SFD pin to assert, signifying a packet reception, captures the assertion time, and re-enables interrupts from the ultrasonic receive circuitry. The receiver captures the time of arrival of the next ultrasonic pulse, and uses the time difference of arrival between the SFD assertion and this ultrasonic pulse to calculate the distance between the receiver and transmitter. Each ms time difference corresponds to approximately .34 m.

3. DISCUSSION

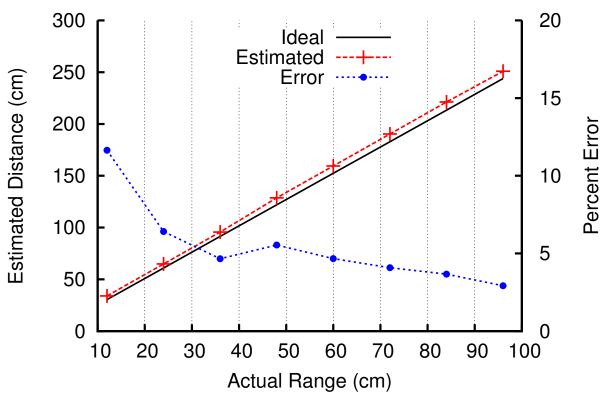

Figure 2: Two nodes directly face and range against one another. We are within 5% error for ranges over .6 m.

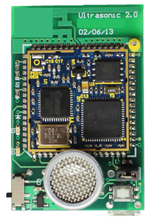

Figure 3: Current platform implementation

Micro-benchmarks validate the ranging accuracy of our system, as seen in Figure 2. Our current implementation weighs 16.4 g with a battery, has a volume of only 5.4 cm^3, and can be seen in Figure 3. Small experiments with students have proven successful, but many research challenges remain.

In areas of high ultrasonic or RF noise, or node density, the nodes should implement a transmission backoff. However, what this backoff scheme should be is unclear. Similarly, the default transmission frequency trades off temporal fidelity and power usage, and it is debatable what the correct balance of longer term study vs more intensive data is.

From an epidemiological standpoint, we offer both a ground truth to evaluate and inform current disease transmission models and the opportunity for more advanced, statistical models that take advantage of the detailed knowledge our system provides. For example, we could easily envision a system that provides a range of possible scenarios depending on how popular patient zero is.

4. REFERENCES

[1] N. Eagle, A. Pentland, and D. Lazer. Inferring friendship network structure by using mobile phone data. *Proceedings of the National Academy of Sciences of the United States of America*, pages 15274–15278, 2009.

[2] A. C. et al. Measuring social networks in British primary schools through scientific engagement. *Proceedings of the Royal Society B: Biological Sciences*, May 2011.

[3] M. et al. The annual impact of seasonal influenza in the us: measuring disease burden and costs. *Vaccine*, 25, 2007.

[4] M. S. et al. A high-resolution human contact network for infectious disease transmission. *Proceedings of the National Academy of Sciences (PNAS)*, Dec. 2010.

[5] L. M. Glass and R. J. Glass. Social contact networks for the spread of pandemic influenza in children and teenagers. *BMC Public Health*, 2008.

[6] E. Yoneki and J. Crowcroft. EpiMap: Towards quantifying contact networks for understanding epidemiology in developing countries. *Ad Hoc Networks*, 2012.