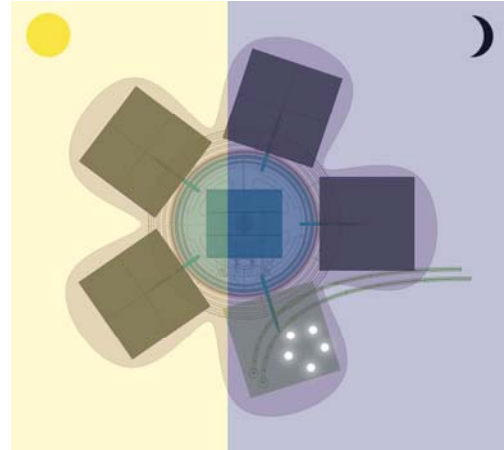


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MAS.836 Final Project



Placing Pixels: Acoustic Sensing for Distance Measurements

Introduction

What are Urban Pixels?

“Urban Pixels” are wireless, ad-hoc lighting units for cities. Composed of independent, solar-powered units this lighting system provides a programmable and distributed interface for achieving lighting effects in the city that blurs the boundary between urban lighting and display. It can be applied to existing buildings, infrastructure and temporary structures in the vertical and horizontal planes. Placed in different configurations such as lines, fields, patterns the Pixels create an additional layer of lighting in the city that can be programmed to convey meaningful information and ambient mood effects through different behaviors.

The Problem

The Urban Pixels system is intended to behave as a determined display where each pixel can be addressed. However, there are no wires between units to support networking. Nevertheless, users should be able to rearrange the pixels on the fly. This feature requires ad-hoc network configuration through localization of each pixel.

This project explores how acoustic sensing and ultrasonic sensing in particular may be applicable to unit localization by sensing distances between pixels.

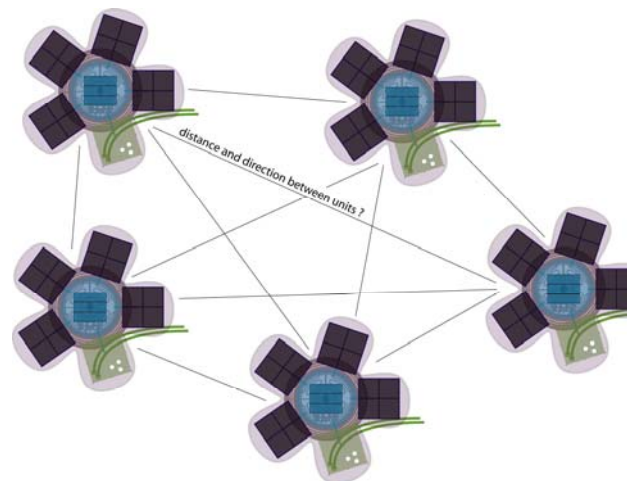


Figure 1. Urban Pixels network which should be reconfigurable on the fly.

Background

This project is grounded in two background areas: acoustic sensing and self localization. Acoustic and especially ultrasonic sensors (frequencies greater than 20 kHz) are frequently used for simple distance measurement (for example, in robotics applications) [3]. There are also advanced examples of outdoor acoustic applications such as the ENSBox [1,2]. Self localization is a large area in the field of sensor networks [see overview in section 2.2 of reference 1]. Both outdoor systems such as the ENSBox [2] and indoor systems such as the Pushpin Computing project [6] have been developed for ad-hoc network configuration.

There are several possible strategies for obtaining distance and direction from an acoustic sensing system. Some of the frequently used methods are: (1) measuring time to return of a signal reflected back from an object in the field, (2) determining amplitude strength (RSSI) though this measure is not reliable in all environmental conditions, (3) tracking differences in arrival times on various receivers, (4) comparing amplitudes from a signal on different receivers [J. Paradiso, MAS.836 lecture, 05/17/07]. In this project, distance is measured by multiplying the travel time of a packet by the speed of sound in air (340 m/s).

Design

Sensor Selection

The positioning system should function in an outdoor environment across distances of approximately two to eight meters. On-board sensors (i.e. without external devices) should suffice to allow localization and network configuration to take place. The 40kHz ultrasound MEAS omni-directional piezo film (PVDF) transmitter and receiver pair were selected to perform the distance measurement (Figure 2) because they are quite affordable (\$10 each) and support omni-directional transmission.



Figure 2. PVDF transmitter (Tx) and receiver (Rx) pair. [4, 5]

Transmitter and Receiver Circuits

The transmitter circuit consists of two oscillators built on the LMC 6482 op amp (Figure 3). The first stage controls the on-off cycle of the transmitter. It bursts for approximately 4 ms and then stops transmitting for approximately 70 ms. The second stage produces approximately 40 kHz and can be tuned by a potentiometer to achieve the best results. Both oscillators are separated from a transformer by a 1,000 uF capacitor to negate any DC coupling caused by the 5V supply powering stages 1 and 2. The transformer drives the piezo resonator between 175-200V which it requires to transmit.

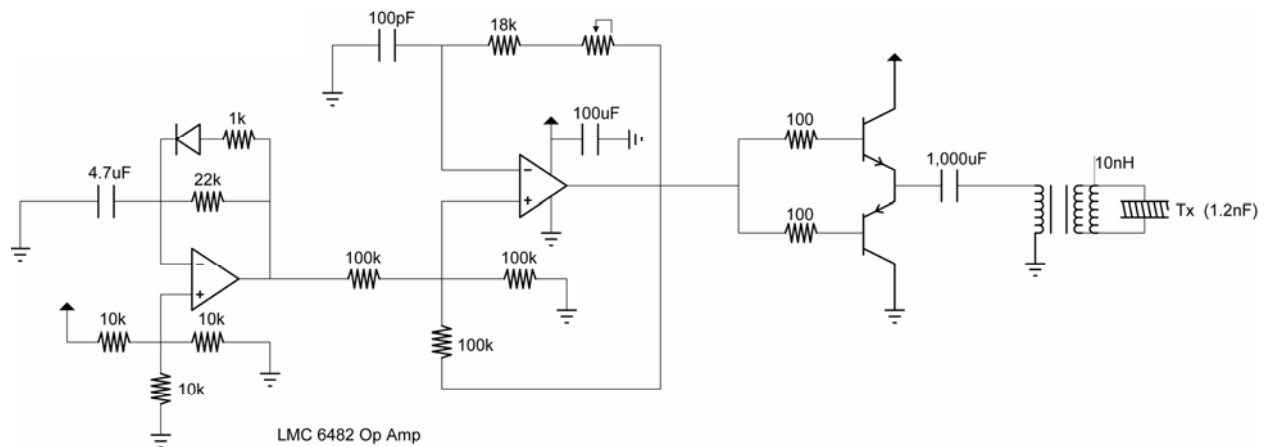


Figure 3. Transmitter Drive Circuit

The receiver circuit consists of four stages which capture the incoming signal. The first two stages filter and amplify the incoming signal. The second two stages detect the rising edge from the signal to produce

a square wave between 0-5V. The receiver's measured impedance value of approximately 174 pF dictates the value of the RC stage preceding the first op amp using the following equation:

$$f = 1/(2\pi RC); \quad f = 40 \text{ kHz}, C = 174.4 \text{ pF}$$

Stages 1 and 2 are built on an LT 1364 op amp¹ which has very low current and voltage noise. Each stage has a bandpass filter between 35 – 50 kHz and a 2.5V bias to center the signal between 0-5V. Stage three consists of an active peak detector followed by a comparator in stage four. The comparator can be tuned to achieve the best response and facilitate measurements. The peak detector has an approximate roll off of $4RC = 22 \text{ ms}$.

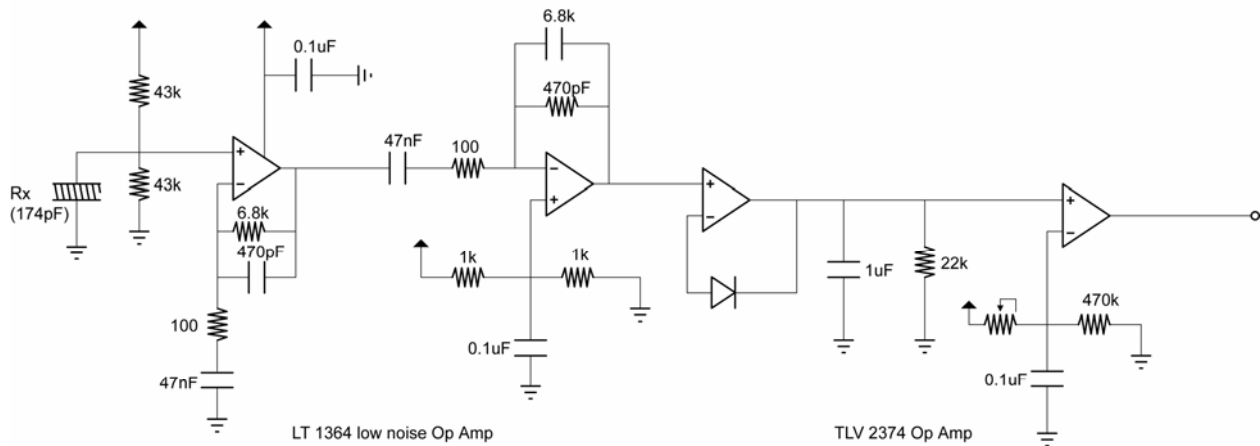


Figure 4. Receiver Drive Circuit

Results

The maximum distance achieved between the receiver and the transmitter (see Figure 5.) was 244' or approximately 20 feet outdoors on grass. At this distance, the signal was still discernable on an oscilloscope from the 50-100 mV of noise. The transmitter was being driven at approximately 200 V and 43 kHz. It may be possible to increase the range by boosting the drive voltage.

The travel time between transmitter and receiver changes linearly with distance. This behavior was measured by recording the time between the rising edge of the oscillator bursts and the arrival time of the packet at the receiver as shown in Figure 6.

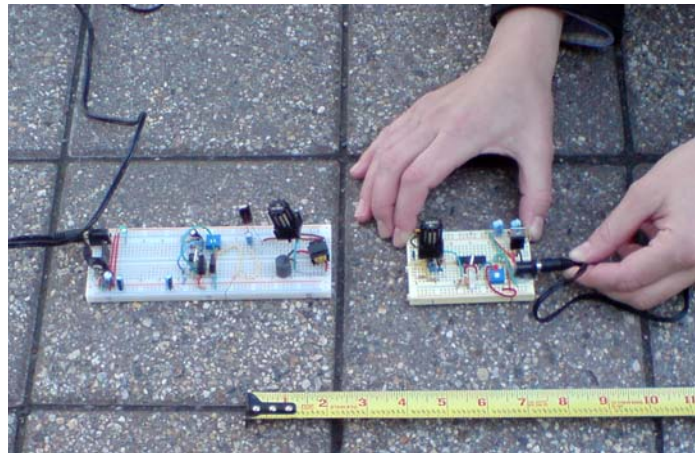


Figure 5. Transmit (left) and receive (right) circuits as built.

¹ See LT 1364 datasheet for detailed information:
<http://www.linear.com/pc/downloadDocument.do?navId=H0,C1,C1154,C1009,C1022,P1106,D2342>

Figure 7 shows the change in signal travel time adjusted for the lag time caused by the transmitter ring up. The response is approximately linear.

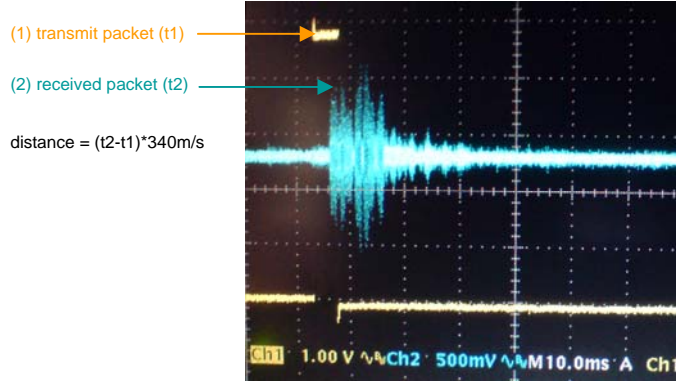


Figure 6. Oscilloscope screen showing the rising edge of the transmitter burst and the arrival of the data packet.

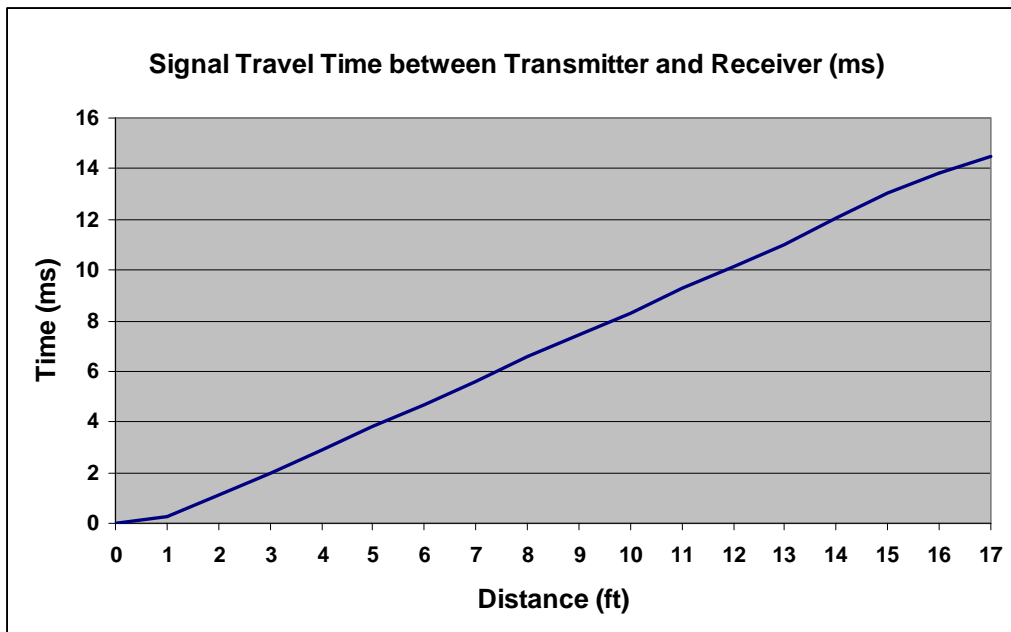


Figure 7. Approximately linear response of transmitter-receiver over distance.

The transmitter consumes a significant amount of power. The average power consumption was calculated to be 250 mW. This measurement was taken by measuring the voltage across a 1 ohm resistor between the transformer and ground. The current was measured by measuring the peak to peak voltage at 800 mV. Current and voltage were in phase making it possible to calculate the power consumption using the equation:

$$\text{Avg. Power Consumption} = \frac{1}{2} V_p I_p.$$

Discussion and Future Work

The sensors were able to span a significant distance though greater ranges may be achieved by driving the transmitter at higher voltages. The sensors are omni-directional which significantly decreases the efficiency of the communication, but facilitates flexible placement of sensor nodes. For the Urban Pixels application, however, directed transmitters and receivers may be more effective for positioning. In combination with RF communication, for example, these ultrasound receiver and transmitter pairs could be used to effectively measure the distance between two units. When the acoustic signal is transmitted a radio chirp is sent to the adjacent units. This signal marks the start time on a counter in the microcontroller which is stopped when the signal reaches the other ultrasound sensor. Future work will involve experimenting with other acoustic sensors and placing multiple sensors onto a single unit to obtain direction in addition to distance information.

Acknowledgements

I would like to thank Mark Feldmeier for his assistance and guidance throughout this project.

References

1. Ali, A., Collier, T., Girod, L., Yao, K., Taylor, C., & Blumenstein, D. Acoustic source localization using the acoustic ENSBox. <http://www.lecs.cs.ucla.edu/~girod/aensbox/>
2. Girod, L., Lukac, M., Trifa, V. & Estrin, D. The Design and implementation of a self-calibrating acoustic sensing platform. *Proceedings of the ACM Conference on Embedded Networked Sensor Systems (SenSys 2006)*, Boulder, CO. November, 2006.
3. Massa, D. Choosing an ultrasonic sensor for proximity or distance measurement. *Sensors*. 1999. Part 1: <http://www.sensormag.com/sensors/article/articleDetail.jsp?id=321383> and Part 2: http://www.sensormag.com/articles/0399/0399_28/main.shtml
4. Measurement Specialties. *Piezo Film Sensors: Technical Manual*. <http://www.meas-spec.com/myMeas/download/pdf/english/piezo/techman.pdf>
5. Measurement Specialties. *40 kHz Ultrasound Omnidirectional Transmitters/ Wide Angle Receivers*. http://www.meas-spec.com/myMeas/download/pdf/english/piezo/40khz_ultrasound.pdf
6. Responsive Environments Group. *PushPin Computing Project*. MIT Media Lab.