Sensor Network and UAV Data Collector

Ivan Hebrio
Dept Electrical Engineering,
University of California Davis
iphebrio@ucdavis.edu

Justin Yau
Dept Electrical Engineering,
University of California Davis
jcyau@ucdavis.edu

Kim-Thu Pham
Dept Electrical Engineering,
University of California Davis
ktpham@ucdavis.edu

1. ABSTRACT

In this project, we implement an innovative remote data gathering solution which uses unmanned aerial vehicles to connect to sensor nodes. This solution is intended to reduce power consumption of remote sensing units (thus increasing lifespan) and to add functionality to remote sensing systems.

2. PROJECT DESCRIPTION

Wireless sensors and sensor networks show a great potential in agricultural and environmental applications where persistent and pervasive sensing and monitoring are needed. Although technology development in this area has resulted in ever smaller and more capable sensors and processors, the limited battery life of unattended sensors remain an open challenge to practical implementation of wireless sensor networks over large areas. Adding to the problem is the requirement to transmit and received the sensed data over long distance.

Autonomous and unmanned aerial vehicles (UAVs) provide a promising solution to the above challenges. Low flying UAVs can be used to read data from a remote sensor within short distance therefore saving precious battery energy on the sensor.

The purpose of our device will be to gather data from ground sensors while flying over an agricultural area. Our system will likely be used by farmers who want to automate their crop monitoring processes. Our main challenge is to ensure that data from the sensors is transmitted and received at a rate high enough such that the quadcopter does not have to hover to wait for data. Goals include reducing pairing time between devices, ensuring proper data transfer, and maximizing power efficiency of both the data transmitter and receiver.

If successful, we will improve on the current state of development by using a widespread data communication method that allows us to access data from any Bluetooth enabled device. We will also have reduced the power consumption of agricultural monitoring systems by reducing the time sensor systems spend ”on” and the power consumption of data receiving devices.

3. SYSTEM OVERVIEW

The system is separated into (1) a receiver and (2) multiple beacons. The receiver is mounted on a quadcopter and receives data from the beacons in its proximity. The beacons periodically store data from their sensors and then transmit data when the receiver is nearby. Both system will have PSoC 4 BLE for communication between each other and a 2.4GHz dipole antenna for an omnidirectional bluetooth signal.

3.1 Beacon Design

Beacons are placed on the ground to measure humidity, moisture, temperature, and ambient light. The goal for the beacon design was to extend the device life by reducing power usage and using solar power to recharge the system. The system enters active mode only when taking measurements or sending data to the receiver. Solar panels that can output a current higher than 15 mA, which is a requirement for PSoC 4 BLE active mode, and a voltage output of at least 2.65 V to reach the minimum voltage output setting of the power management IC are required to recharge and use the system. The power management integrated circuit from Cypress manages the system power by charging large storage capacitors, switching between battery power and solar power, and supplying power to the controller.

Each beacon has a rotary switch which can be used to change the unique ID of the beacon. A flash memory that can large amounts of data to reduce the frequency of flying the drone to collect the data.

3.2 Receiver Design

The receiver is mounted below the quadcopter and collects data from the beacons during flight. The receiver consists of two controllers: a PSoC 4 dedicated to Bluetooth communication with the beacons and a PSoC5 dedicated to data storage and communication to the flight controller. The PSoC controllers communicate with shared UART lines. Once data is received through Bluetooth on the PSoC 4, it is sent to the PSoC 5 and stored on an SD card. The PSoC 5 interfaces with the flight controller, an Intel Edison board, through simple shared GPIO pins. When the quadcopter connects to a beacon, the PSoC 5 alerts the flight controller to slow down. When data collection from the beacon is complete, the PSoC 5 notifies the flight controller again to resume normal flight.

4. SENSORS

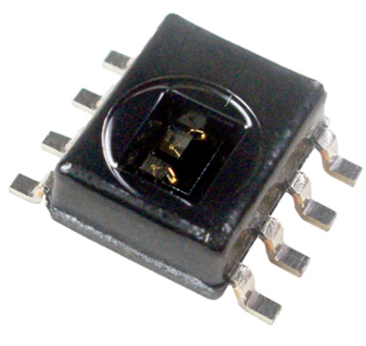


Figure 1: Temperature and Humidity Sensor

4.1 Sensor: Humidity and Temperature Sensor

The HIH6030 by Honeywell senses temperature and humidity and converts the data digitally. The sensor has a temperature operating range of -40C to 125C and a relative humidity range of 0 to 100 percent, which is perfect for outdoor applications.

4.2 Sensor: Ambient Light Sensor

The TEMT6000X01 by Vishay Semiconductors is an ambient light sensor with a high sensitivity of 50uA. Paired with a 10k resistor, the sensor is able to detect a wide range of illuminance from the darkest night to the brightest day.

4.3 Sensor: Soil Moisture Sensor

The SparkFun Soil Moisture Sensor is a simple sensor which detects the conductivity of two leads submerged in the ground. The conductivity should correlate with the moisture levels of the soil, but the sensor should be calibrated for different types of soil. The sensor is easily powered with 3.3V and gives data as an analog signal between GND and VDD, higher voltage means higher moisture.

5. SYSTEM DESIGN

5.1 Power Analysis

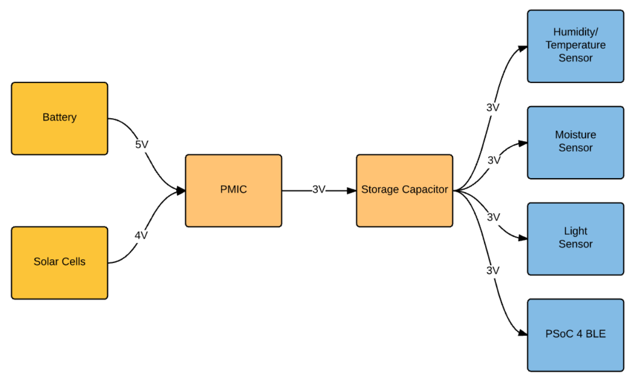


Figure 2: Power Diagram

Beacon Power Usage: The beacon collects data at a certain interval, per minute or per hour, depending on the user's specification. In between data collection, the beacon stays in low power mode and be able to still be detected by the Quadcopter.

Quadcopter Data Usage: The user will have the ability to choose whether the PSoC is turned on or off depending if the data collection is needed when using the quadcopter.

The calculations for the ground sensors were done assuming data would be collected 48 times per day (two times per hour), the PSoC alternates between deep sleep and active mode, and the sensor is only on during the time it is taking measurements.

Power calculations are shown at the end of the document.

5.2 Communications

See Figure 3.

The temperature and humidity sensor communicates to the PSoC 4 BLE using I2C while the light and moisture sensors in the beacon SAR ADC. The data from these sensors are stored and read in flash memory through SPI. The data is sent to the receiver through 2.4 GHz Bluetooth low energy. The PSoC 4 BLE in the receiver uses UART to send the data to PSoC 5 and then get stored in an SD card using SPI communication.

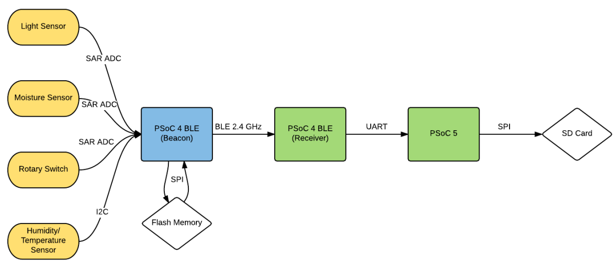


Figure 3: Communications Diagram

5.3 Enclosure Design

See figure 13 for an example of our enclosure. We designed a custom enclosure for our beacon and chose a GoPro camera mount as the enclosure for our receiver.

The GoPro mount was a convenient and practical choice because the size of our receiver board was similar to that of a GoPro. Securing the receiver to the quadcopter frame was as simple as securing a camera.

Our beacon enclosure went through several iterations. We designed the enclosure based on the idea that the beacon should be protected from sun, wind, and rain but should still be able to give accurate measurements of the local environment. Weather stations were an ideal model for our design because their enclosed sensors must be protected from the elements but still measure temperature, moisture, and humidity. An example is shown in figure 14.

Our first few versions of the beacon enclosure had slanted openings to ensure accurate humidity and temperature readings. However, for testing purposes, we opened the sides of the encasing to make our LED indicators more visible and the beacon board easier to access.

6. DEVICE FIRMWARE

6.1 System Diagram

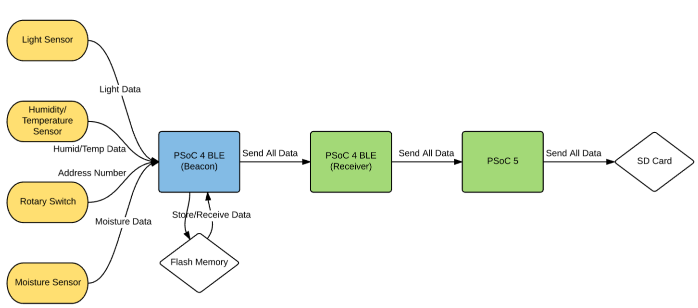


Figure 4: System Overview

6.2 Signals Chart

See figure 5 and figure 6.

Beacon: The sensor data is read and time stamped by the PSoC 4 BLE and stored in Flash memory. PSoC will access this stored data and send it to the drone when its receiver connects and demands data. The rotary switch is for manually changing the address of a beacon for the receiver to differentiate between multiple beacons.

Receiver: The receiver will contain the current time and use that as a base to help timestamp data. When it connects to a beacon, it will ask for data and send this data to an onboard PSoC 5 which in turn will store the data in an SD card.

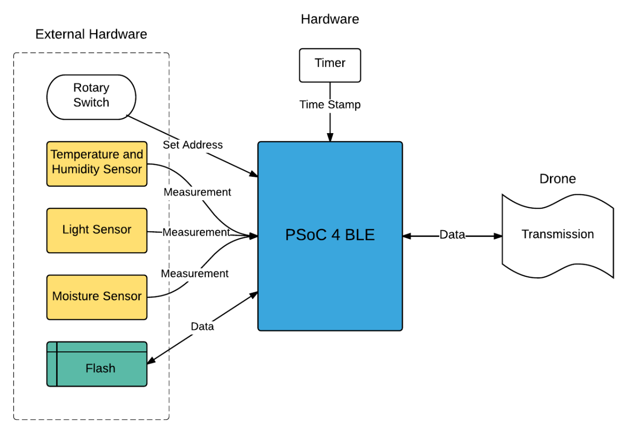


Figure 5: Beacon Signals Chart

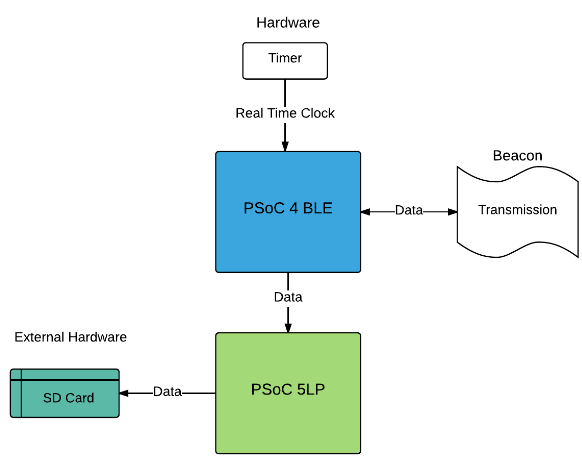


Figure 6: Receiver Signals Chart

6.3 State Machine

See figure 7 and figure 8.

Beacon: The beacon will start in sleep mode when reset or just turned on. When the timer interrupt occurs, the beacon will request, read, and store data into flash memory. It will then advertise its signal over bluetooth. If the advertising interval times out, then it will return to sleep mode. If it does succeed in connected to the receiver, then it will send all its data to the receiver, disconnect from the receiver, reset all its data, and go back to sleep mode.

Receiver: The receiver will begin in a sleep state and wait for a signal from the Intel Edison to begin scanning for beacons. Once it connects to a beacon, it will receive all the data the beacon receives. Once the beacon disconnects from the receiver, the receiver will then begin to send the data it just received to the PSoC 5 which will in turn store this data into an SD card. After the data is stored, the receiver will begin scanning for beacons again.

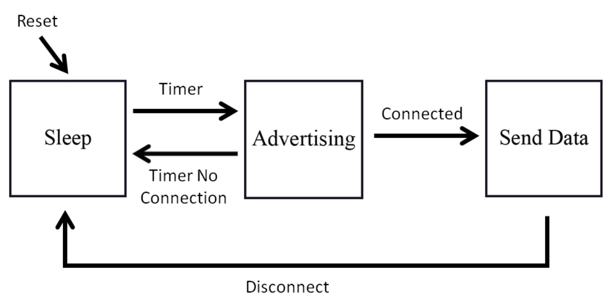


Figure 7: Beacon State Machine

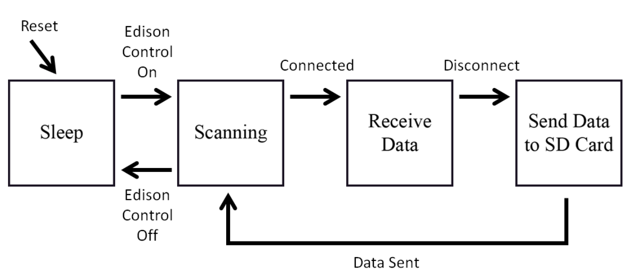


Figure 8: Receiver State Machine

7. END-USER DELIVERABLES

When the user wants to view the data collected, they can take the SD card out from the receiver board and put it into their computer. From there, they will see the text files created from the data (see figure 9) and view it to their liking. Opening a file will present the user with all the data collected from a specific beacon (see figure 10).

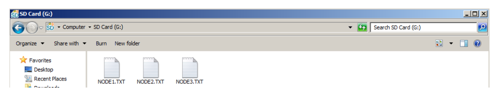
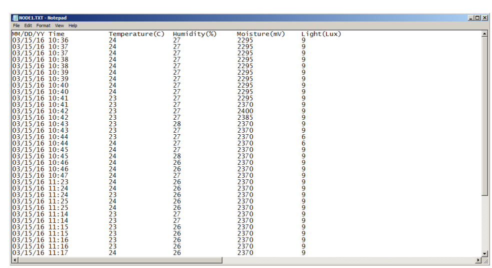


Figure 9: SD Card



MM/DD/YY Time	Temperature(C)	Humidity(%)	Moisture(mV)	Light(Lux)
03/15/16 10:36	24	27	2295	9
03/15/16 10:37	24	27	2295	9
03/15/16 10:37	24	27	2295	9
03/15/16 10:38	24	27	2295	9
03/15/16 10:38	24	27	2295	9
03/15/16 10:39	24	27	2295	9
03/15/16 10:39	24	27	2295	9
03/15/16 10:40	24	27	2295	9
03/15/16 10:40	24	27	2295	9
03/15/16 10:41	23	27	2295	9
03/15/16 10:41	23	27	2370	9
03/15/16 10:42	23	27	2400	9
03/15/16 10:42	23	27	2385	9
03/15/16 10:43	23	28	2370	9
03/15/16 10:43	23	27	2370	9
03/15/16 10:44	23	27	2370	6
03/15/16 10:44	24	27	2370	6
03/15/16 10:45	24	27	2370	9
03/15/16 10:45	24	28	2370	9
03/15/16 10:46	24	26	2370	9
03/15/16 10:46	24	26	2370	9
03/15/16 10:47	24	27	2370	9
03/15/16 11:23	24	26	2370	9
03/15/16 11:24	24	26	2370	9
03/15/16 11:24	23	26	2370	9
03/15/16 11:25	24	26	2370	9
03/15/16 11:25	24	26	2370	9
03/15/16 11:14	23	27	2370	9
03/15/16 11:14	23	27	2370	9
03/15/16 11:15	23	26	2370	9
03/15/16 11:15	23	26	2370	9
03/15/16 11:16	23	26	2370	9
03/15/16 11:16	23	26	2370	9
03/15/16 11:17	24	26	2370	9

Figure 10: Beacon Data File

8. PROJECT BUDGET

See figure 11 and figure 12.

Beacon: The beacon cost $66.76 to create, with the breakdown of each category close to one another. The main hub cost the most compared to the other categories of the beacon because of the PSoC 4 BLE chip and the dipole antenna used for bluetooth communication. Power followed closely behind in cost due to the use of a solar cell, PMIC, 150mAh LiPo battery, and a couple storage capacitors.

Receiver: The receiver board side of the project cost $42.03 to assemble, with the main hub taking a majority of the costs. This is due to the main hub housing a PSoC 4 BLE chip, PSoC 5 chip, a 2.4GHz dipole antenna, and an SD card.

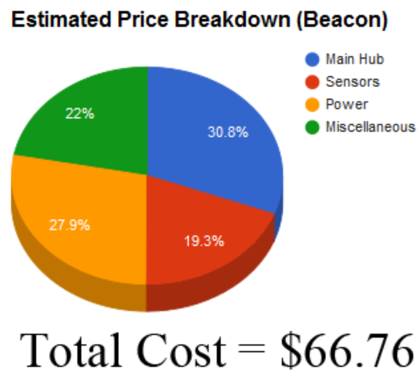


Figure 11: Cost Estimate (Beacon)

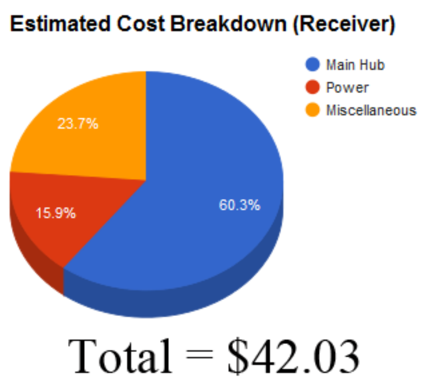


Figure 12: Cost Estimate (Receiver)

9. TEST SET-UP

We tested our project with an experimental setup in Kemper Hall. Beacons were placed in plant pots approximately 10 meters apart to avoid overlap between the Bluetooth signals of each beacon. The beacons gathered data on soil moisture, humidity, temperature, and

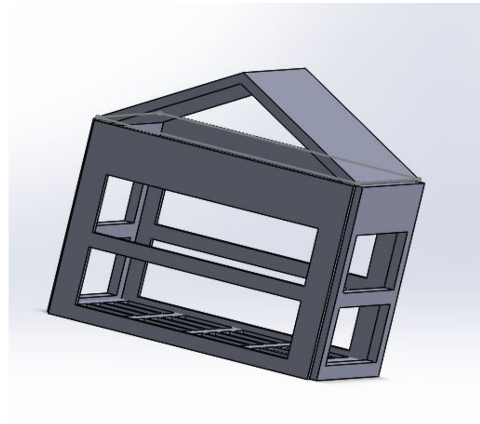


Figure 13: Beacon Encasing

ambient light. We mounted our receiver on a Turnigy Talon Quadcopter frame containing a Pixhawk flight controller and an Intel Edison offboard computer. The receiver was connected to the Intel Edison through two GPIO pins.

Starting at one end of the hall on the ground floor, we walked the quadcopter to the other end past all of the beacons (for safety purposes we did not attach propellers to the quadcopter). As the quadcopter neared each beacon, LED light changes on the receiver and on the beacons indicated bluetooth connectivity and successful data transmission. Results of our test are shown below.

10. RESULTS AND DISCUSSION

1. Connection with all three beacons was successful
2. Average connection time was (enter time here)
3. The receiver communicated its Bluetooth connection status to the Intel Edison flight controller
4. Data is shown in the figure 10.

s antenna to a directional antenna for increasing the range and From the results, we can conclude that our test was successful in demonstrating data capture from sensors, data transmission over wireless connection, and multiple connections and disconnections to the beacons.

10.1 Future Directions

In future iterations of the project, we would implement features to improve the efficiency and expand the scope of application of the project. We can change the receiver's antenna to a directional antenna for increasing the range

To improve the efficiency of the system, we would change the wireless communication from Bluetooth to one that is more suited for sensor networks- such as Zigbee. Zigbee uses the same 2.4 GHz frequency to transmit but is specifically suited to small-packet de-

Figure 14: An example of encasing

vices. Zigbee has a larger transmission range (50m) than Bluetooth and is low cost. However, the major advantage of Zigbee over Bluetooth is its configurability for behavior as a beacon in a number of network topologies.

Zigbee devices provide the option of being configured in beacon or non-beacon mode. In beacon mode, devices sleep for a set period of time and broadcast for short periods. The coordinator device is battery powered and connects to the beacons only when necessary. These beacon devices can be arranged in a variety of topologies. The most common are star, mesh, and cluster tree network topologies. We would use a mesh network topology with a mobile coordinator device (mounted on the quadcopter). The beacons would communicate with each other, making time synchronization easier between beacons. With Zigbee functionality, the coordinator is also able to assign addresses to the beacon devices- something that we had to implement manually with Bluetooth.

To expand the scope of the project, we could apply the same remote data gathering concept to a variety of fields by changing the type of data and the type of sensors we use. For example, we could extend the project to wildlife studies by remotely monitoring RFID-tagged animals. The quadcopter could be mounted with a tag scanner which communicates with the on-board data logger. A camera could also be mounted on the quadcopter to take pictures of the area as the quadcopter flew through, adding geographical and topological data of the area. The system could be used to track grazing patterns and vital conditions for herds of animals without. Scientists would spend less time driving far into the field and manually gathering data, which leaves more time for information processing and further research.

10.2 Conclusion

During this quarter we demonstrated capability for remote data gathering, wireless connection from a UAV to ground sensors, and automated flight. The combination of these capabilities results in a remote data gathering system can be used to reduce travel time and system maintenance in a number of applications.