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Preliminary Design Report:

Ultrasonic/RF Positioning System

Table of Contents

List of Tables and Figures

Project Abstract

We are going to use a combination of RF and ultrasonic transceivers to design and build a system capable of locating the position of a mobile receiver inside an enclosed room. The system will consist of remote beacons mounted throughout the room and the actual receiver, which could be part of a robot, or utilized in some other fashion. The receiver will use an RF transmitter to request an ultrasonic tone from each of the beacons. The receiver will then measure the time delay from the transmission of the initial RF signal to the reception of the sonar pings. These time delays for each of the remote beacons will be sent to the microprocessor, and the microprocessor will then calculate the receiver's position relative to each of the remote beacons. When the system is set up, it will be calibrated with the location of the remote beacons so that the position relative to the beacons calculated from the time delays can be presented as an actual location within the room.

Features and Objectives

The ultrasonic/RF positioning system can satisfy a valuable need in robotics applications, providing a precise location of where the unit is inside of a room to potentially provide operating information or assist in supplying necessary commands. In order to accomplish this overarching goal, the system must meet the following intermediate objectives:

- Record upon input the location of each of the remote beacons to be placed around the room in order to use them as a reference at the end of the process
- Establish reliable RF communication between the receiver and each of the remote beacons with the ability of the receiver to communicate directly to a specific remote beacon when required
- Implement effective reception of ultrasonic tones by the receiver when they are emitted from the remote beacons
- Allow the receiver to obtain and store accurate timing information for the duration of time which passes between the transmission of the RF

command and the reception of ultrasonic tones from specific remote beacons

- Perform calculations necessary to convert the recorded times into relative distances from specific remote beacons
- Resolve the geometry required to combine the relative distances from each remote beacon with the calibrated positions of each beacon into a specific point in the room which is the location of the receiver
- Provide easily interpretable output informing the user of the actual location in the room of the receiver unit

Components

The ultrasonic/RF positioning system will require the finely-tuned coordination of multiple components: namely, microcontrollers for the beacon and object, RF transmitters and receivers, ultrasonic transceivers, and other supporting circuitry.

THE MAIN INGREDIENTS

Microcontrollers

For the microcontrollers, we have decided upon the Atmega 2560. The biggest concerns were having enough UARTs and timers (for capturing the time differences). Honestly, we could have found other comparable microcontrollers, but the Atmels just seemed the nicest balance of features and easy-of-use.

RF Transmitters/Receivers

To send the instantaneous command to each beacon (and to receive the command) we needed some form of RF transmission and reception. Originally, we were looking at Xbee development kits to handle all of the RF. The ease-of-use in tandem with the vast array of options made them highly appealing, but to our chagrin we found that they make actually be too high tech. Our design relies immensely on our ability to reliably time the transmission of a sound wave. The Xbees have multiple built-in controllers that handle the RF connection, but unfortunately, the timing for transmission may be hampered by higher-end error-correction schemes and counters—what we need is much simpler.

Using some advice, we found RF Links on sparkfun that were very stripped and economical, including only what we need. With a data rate of up to 4800bps and a range of up to 500ft, the RF link is just a simple RF transmitter receiver pair that connects to a UART. The small size and cheap price will help in making multiple beacons more feasible.

Ultrasonic Transducers

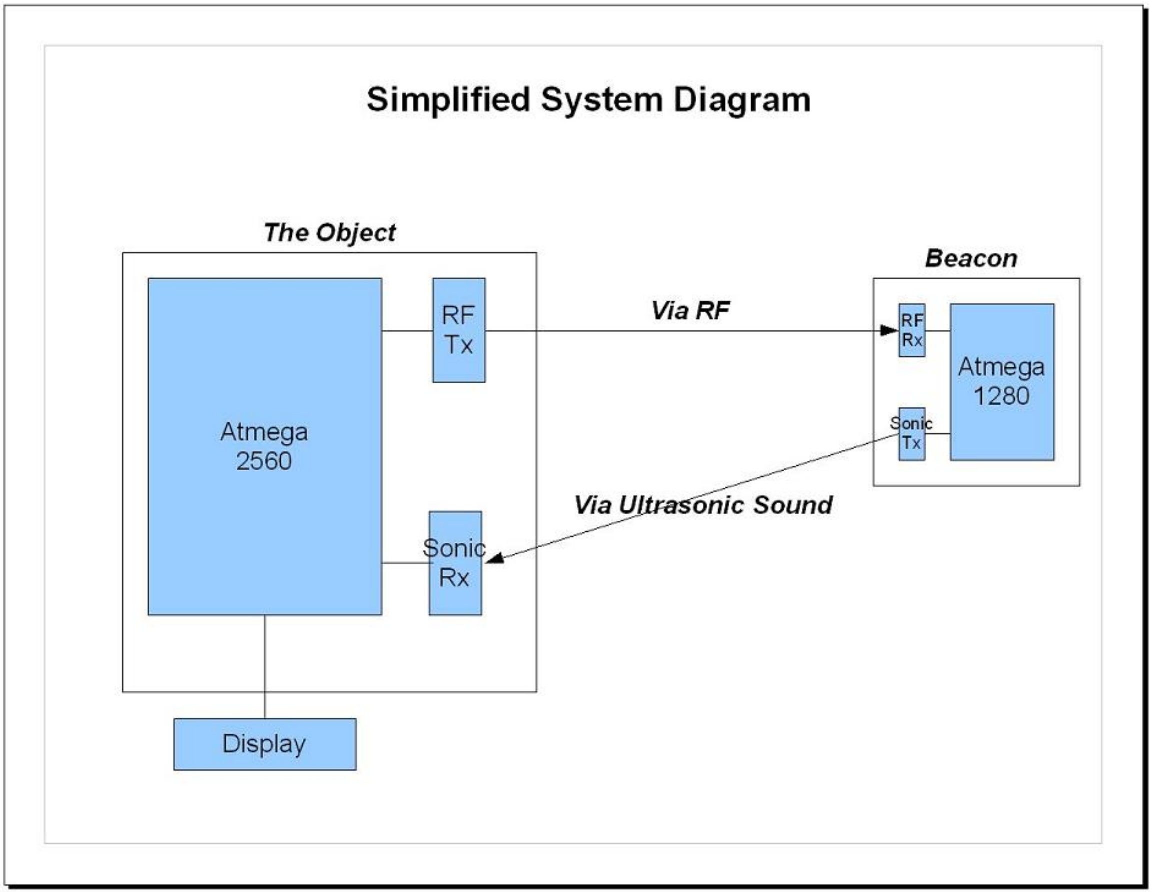
Also from sparkfun, we found ultrasonic transducers that were really inexpensive (great for scaling to multiple beacons). They offer decent range which depends on the applied voltage.

Competition

Smart Robots, Inc is a company which sells autonomous mobile robots in a number of different configurations. They offer a navigator version of their SR-4 robot which has a triangulation base and two remote beacons. This unit can only be obtained as an addition to the professional model. Total cost is approximately $6500, of which $1000 is added on for the navigator functionality which includes the base and two remote beacons. Our system will function independently and be available on its own. Its applications will be limited only by what can receive its output, and our cost will be significantly less than this alternative.

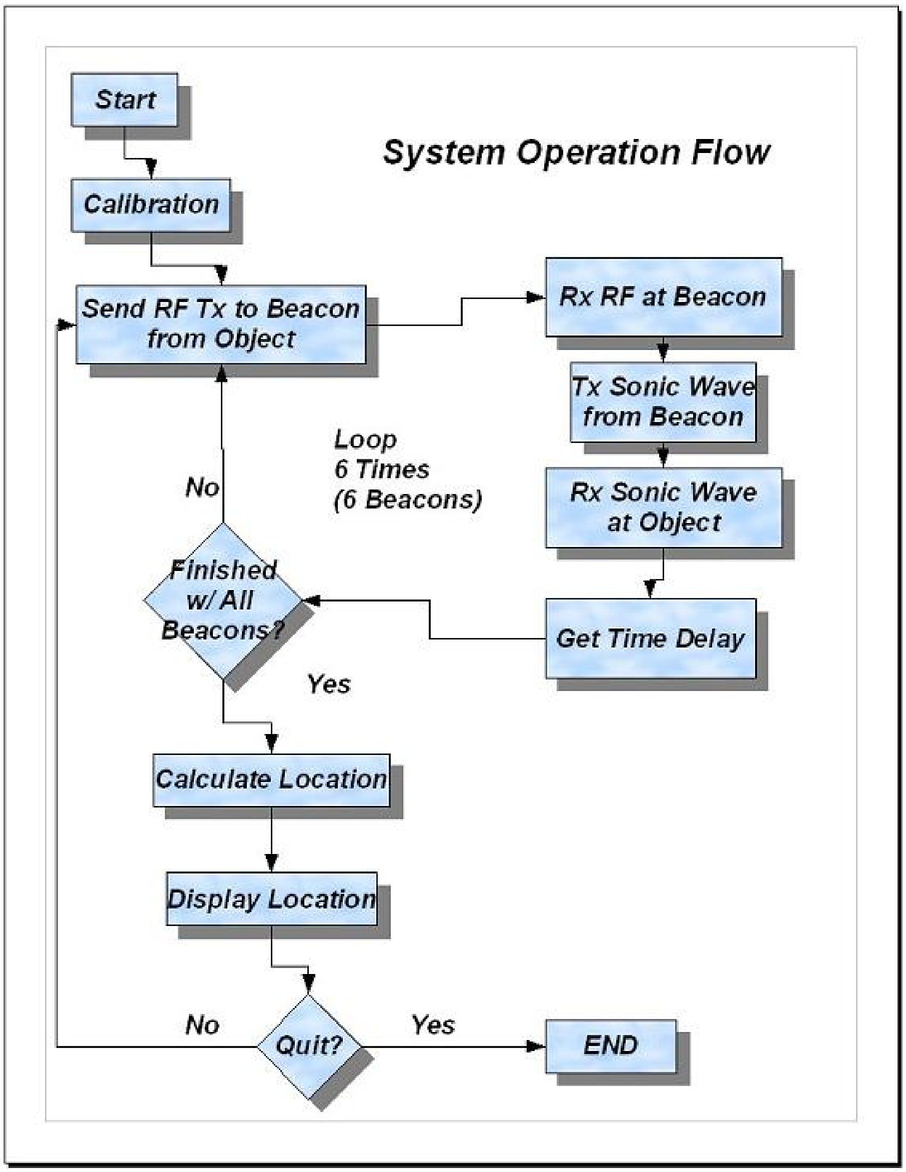
Technical Concepts

There are numerous technical concepts that we will need to overcome in order for this system to function properly. Two way communications between the remote beacons and the receiver is imperative. The receiver must be able to command a specific remote beacon to emit an ultrasonic tone through the RF link, and the receiver must also be able to successfully receive the tone when emitted. Due to the effective receive area of the ultrasonic receivers, there will most likely need to be more than one of them present on the receive unit. Communications on the remote beacon side of the system must also be handled reliably. The beacon needs to correctly receive and interpret the RF signal commanding it to emit its tone. A simplified layout of the object and one beacon is shown below.

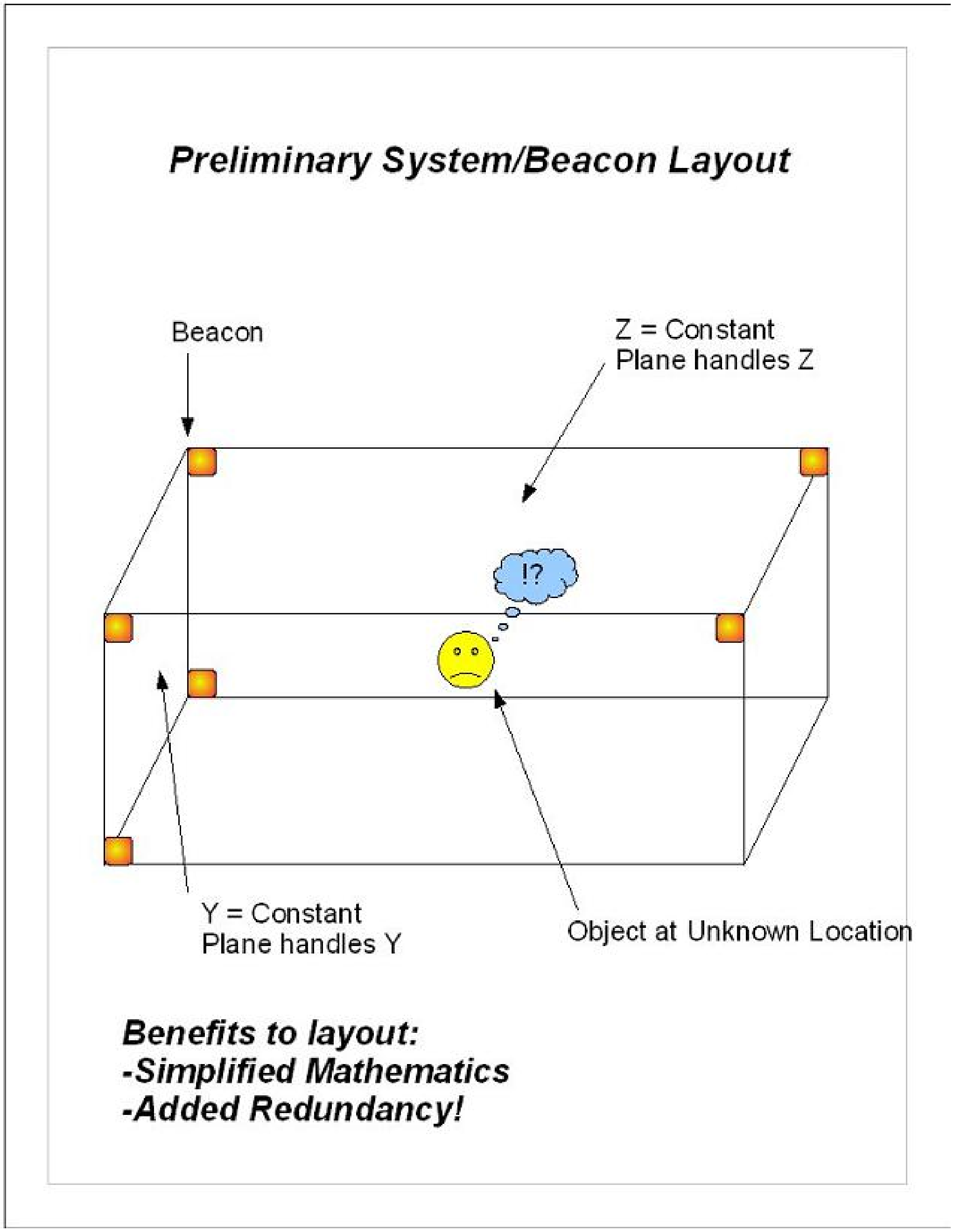


The second issue is receipt of the tones by the receiving unit. Since the receiver does not know where it is at to start, it must provide full coverage to receiver an ultrasonic tone from anywhere in the room, from any direction relative to its orientation. This will most likely require multiple ultrasonic receivers, as outlined above. With more than one ultrasonic receiver present, the processor must be able to resolve the data from *each* ultrasonic receiver when a tone is received and consolidate this into one accurate time delay. Additionally, the receiver will also need to ignore any echoes which might occur causing secondary tones to be received after they have bounced off of walls, floor, ceiling, etc.

Third, the issue of timing must be successfully resolved. Since all of our location calculations will be based on the timing measurements obtained by the reception of ultrasonic pulses these times must be very accurate. The delay on the remote beacon between reception of RF signal and emission of ultrasonic tone must be kept constant so that it can be accounted for reliably. Also, the processor in the receiver needs to be able to run multiple concurrent timers and store multiple values from them. This will allow each of the remote beacons to be timed coming into each of the ultrasonic receivers on the receive unit. A slightly more detailed chart of the entire process is shown below.



`	Next, the geometry involved in the position calculation must be specified completely for the processor. Even after all of the above challenges have been successfully addressed we will be left with a list of distances from the receive unit to each of the remote beacons in the room. These distances, together with the known positions of each of the remote beacons (provided during the initial calibration and set-up) will be enough information to supply a definitive location in the room. Specifying the relationship between the relative distances, beacons positions, and location of receiver is pure geometry, but not necessarily simple. A preliminary room layout for the system (beacons) is shown below.



Finally, we must present our information in an easy format for a user to read so that when the system is implemented it will present the location of the receiver inside of the room in which the system is deployed. There are a few ways this can be accomplished, and most likely our choice will be determined by time constraints and how much time, effort, and money are required to complete the rest of the issues in this list.

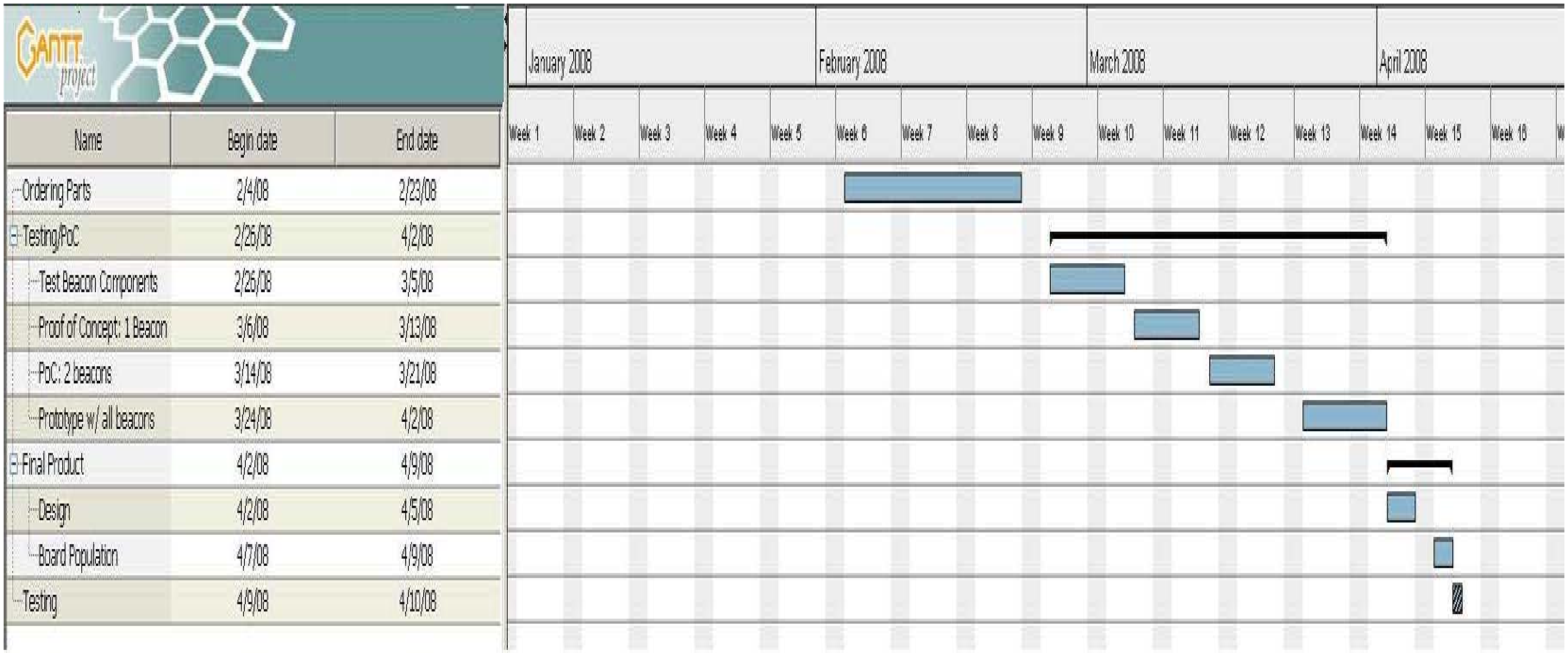
Power and size will not be an issue for this project, since we are not constrained (within reason) on either the remote beacons or the receiver unit. If we were designing this system for a specific robot or application, then power and size constraints would come from the framework into which the system is required to fit. Since our system will be free-standing and independent, we are not concerned with these issues at the current time.

Gantt Chart and Division of Labor

The following is a rough division of labor,

Steven	***Bret***
RF Transmission/Reception	Ultrasonic Transmission/Reception
Object Atmel programming	Beacon Atmel programming
Prototype Construction	Prototype Construction
Object Board	Beacon Board
Testing/Debug	Testing/Debug

The following Gantt chart is an estimate for the project's timeline,



GANTT project
Name
Begin date
End date
Ordering Parts
2/4/08
2/23/08
Testing/PoC
2/26/08
4/2/08
Test Beacon Components
2/26/08
3/5/08
Proof of Concept: 1 Beacon
3/6/08
3/13/08
PoC: 2 beacons
3/14/08
3/21/08
Prototype w/ all beacons
3/24/08
4/2/08
Final Product
4/2/08
4/9/08
Design
4/2/08
4/5/08
Board Population
4/7/08
4/9/08
Testing
4/9/08
4/10/08
January 2008
February 2008
March 2008
April 2008
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
Week 12
Week 13
Week 14
Week 15
Week 16