Robot Guidance Using Beacons

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Abstract

The purpose of this report is to detail the design and implementation of a robot navigation system through the use of beacons. The project entailed the design and construction of a robot with the capability of determining its location in reference to known reference points. The implementation involved the use of ultrasound to determine the distance between the robot and known reference points. From these distances the Cartesian coordinates for the robot's location along the horizontal plane where determined. The produced robot was capable of navigating within a 2m by 2m square area successfully with a resolution of 2.23 cm. Possible sources of error can be attributed to round of error due to the conversion from floating point to integer as well as errors within the infrared transmitters used to synchronize beacon transmission.

Acknowledgment

I would like to first acknowledge the help and support Professor Hiscocks gave me throughout this project. Additionally, I'd like to thank Kim Woon-Fat and Gordon Lau for being my sounding boards. Finally I'd like to thank my parents for bearing with me during this last semester. Mom, Dad, I'll be home in May.

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Chapter 1

Introduction

It is important to develop mobile robot navigation in order for robots to successfully interact within our environment. Currently, methods involving robot navigation consist of determining the robot position using either relative position measurements or absolute position measurements. Relative position measurements usually use wheel rotation measurements or gyroscopes to determine the robot's position. The problem with this method is that it utilizes previous measurements in determining the new position of the robot. Since each measurement contains an amount of error, eventually the new measurement will become useless. The use of absolute position measurements involves external reference points and therefore ignores this problem. A common approach to create external reference points, involves the use of beacons.

The objective of this report is to detail the design and implementation of a robot navigation system utilizing active beacons. This particular application involves the determination of distance between the robot and the beacons using ultrasound. These measurements were then used to trialate the absolute position of the robot within its field of operation relative to the known positions of the beacons. The distance measurements were obtained through the use of Time of Flight (TOF) measurements obtained from ultrasound transmission. Ultrasound consists of sound waves beyond the 20kHz frequency range, which makes it suitable for distance measuring within a range of a few meters. Additionally, the beacons were synchronized through the use of a wireless infrared controller.

The scope of this report is intended for the electrical engineering audience. Additionally, this report will be relevant to readers requiring a general understanding of active beacons for the purpose of robot navigation. This report will detail the theory behind the principles of robot navigation, the specifications required for the design, the design of the hardware and software components and a summary of the operational results of the final design.

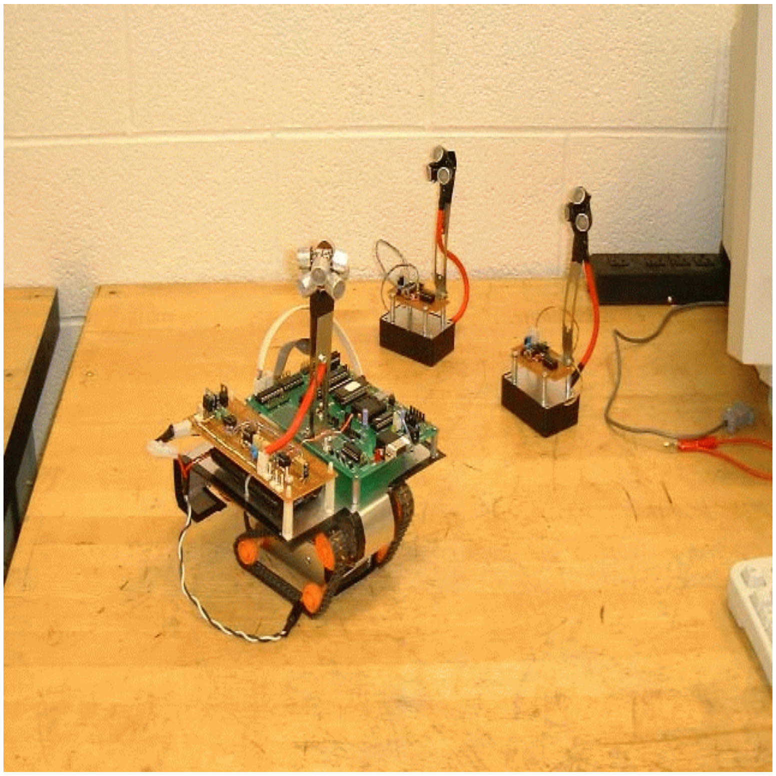

Figure 1.1: Picture of Robot and Beacons

Chapter 2

Theory

2.1 Types of navigation

Autonomous navigation systems can be applied to many applications, each involving their own requirements for both software and hardware. The hardware requirements are usually related to the scale of the navigation in question. It becomes practical to categorize the methods of navigation within the scale of the operational environment of the device. These categories were obtained from Dixon [6] and are listed as follows:

- Global Navigation: Navigating the device within large distances, typically within entire geographical regions.
- Local Navigation: Navigating the device within a local environment, usually bounded by reference points. This consists mainly of navigating relative to other objects in order to interact with them.
- Personal Navigation: Navigation of various parts of the device relative to the device itself. Consists of mainly navigating parts of the device relative to other objects in order to interact with them.

Typically, global navigation consists of using GPS systems to determine the position of the device relative to the planet itself. Navigation within the local environment typically consists of the application of a robot within a workspace. Commonly, the robot may utilize proximity/tactile detection, path detection or beacon detection as forms of navigation. Multiple uses of personal navigation consist mainly of navigating robotic arms or appendages in order to interact with the surrounding environment.

2.2 Types of Beacon Navigation

Navigation within local environments may be comprised of various methods however this report addresses the use of navigation relative to beacons. Navigation relative to beacons utilizes the distance or direction between the robot and several beacons in order to determine the position of the robot relative to the beacons. If the beacon positions are known, the robot will be able to recognize its own position within its operational environment. Beacons may consist of active beacons, passive beacons, or optical reference points.

In order to determine location relative to a series of beacons the robot may utilize either triangulation or trialation. Triangulation refers to the use of the angle measurements between the robot and the various beacons while trialation uses distance measurements.

An active beacon is a system where the beacon transmits its location, through a signal, to the robot. This usually consists of ultrasound or radio transmitters, which are synchronized either by a central beacon controller or by the robot itself. The robot detects the transmissions of these beacons and uses either the distance (calculated through TOF measurements) or angle measurements to determine its position.

A passive beacon system reflects a transmitted signal directed from the robot and reflected by the beacons. Implementation of the passive beacon system consists of reflectors distributed throughout the environment. The robot then transmits a pulse, which is then reflected back towards it self. The pulse is then measured for angle or distance. An important requirement for a passive beacon system is that the beacons be distinguishable, either through varying reflective qualities or in conjunction with dead-reckoning techniques used within the robot.

A visual beacon system consists of using visual reference cues in order to determine the location of the robot. The robot thus utilizes 360 degrees of vision to determine the location of various known landmarks. This information may then be used as reference points in determining position. It is an important requirement for the vision system to monitor the angle between the face of the robot and the camera. This is necessary for the robot to perform triangulation measurements. Other methods involve the use of dual cameras to formulate distance between the robot and the landmark.

2.3 Triangulation and Trialation

The use of triangulation involves the detection of angle between the point of measurement and a series of known reference points. The calculations of the x-y coordinate system are derived from the known values of distance and angle between the beacons.

The use of trialation involves the detection of the distance between the point of measurement and a series of known reference points. The calculations for the X-Y coordinate system can be derived from the distances between the point and the reference points and the distance between reference points. The figure 2.1 and equations 2.1 and 2.2 show how the x and y coordinates are calculated.

$$x = (D_1^2 - D_2^2 + D_3^2)/(2 * D_3) \tag{2.1}$$

$$y = \sqrt{(}x^2 - D_1^2) \tag{2.2}$$

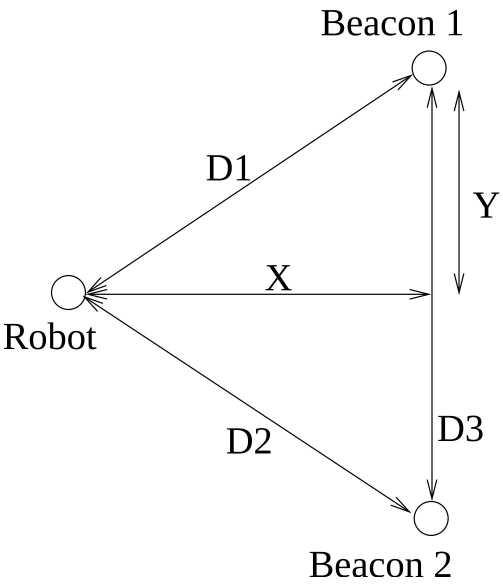

Figure 2.1: Trialation Calculations

Chapter 3

Specifications

3.1 Objective

The objective of this design project was to design and construct a robot which can determine its location along the horizontal plane. The mechanism for determining the location consisted of using known reference points in the form of beacons. In order to determine the robot's location, it will use the distance between itself and the beacons to trialate its position relative to the beacons. The constructed robot will use its determined position to navigate within its surroundings.

3.2 Specifications

The design consisted of a single robot and two active beacons. The robot was required to determine its location in reference to these beacons. Once the location was calculated, it was used to navigate the robot within its bounded environment. Distance measurements between the robot and the beacons were determined through the use of ultrasound TOF (Time of Flight) measurements. Through the use of infrared encoders/decoders, the robot controlled the individual beacons. A microprocessor was used to perform the triangulation calculations, beacon control and motor control. The accuracy was defined to be +/- 1cm within a total area of 2m by 2m. The consistency of the measured results was determined to be more important than the accuracy of the coordinates. Additionally, since the robot could not simultaneously move and measure location, the measurement time was required to be below

1 second.

3.2.1 Navigation Requirements

The ultimate purpose of this design project was to create a robot which could determine its position within the two-space of its operation. In order to meet this requirement, a definition for the minimum grid size necessary for the robot, needed to be defined. The grid size can be derived from two factors: the dimensions of the robot, and the traveling distance between measurements. The dimensions of the robot in question were limited by the size of the components used and the minimum size required would be at least 10cm x 10cm. Since this block size is quite large, the limiting factor becomes the distance moved between measurements. The distance moved between measurements is relative to the dimensions of the robot. The maximum value of the distance moved is limited to half of the dimension of the robot along the direction of movement. Therefore, the accuracy of the navigation would require the robot to be placed within a grid measuring 5cm x 5cm or larger, assuming that the dimensions of the robot are at least 10cm x 10cm. In order to distinguish between points of the grid, an error of 2.5 cm was allowable. Since the actual dimensions of the robot were within 20cm x 20cm, it was possible for the actual error to be greater than 2.5 cm however, the original estimate of allowable error was maintained.

3.2.2 Robot Requirements

The robot was required to detect transmitted ultrasound, control the beacons, perform the triangulation calculations and control the motor speed and direction. These elements were self-contained within the robot.

A micro controller was necessary for control purposes and triangulation calculations. In order to control the motors and beacons, 7 output pins were necessary (3 for beacon control, 4 for motor control). The triangulation calculations required square root operations in order to calculate the X-Y coordinates. Therefore, either a square root algorithm or a floating-point math package could have been used.

The design was required to detect the shortest distance between itself and the beacons. In order to use ultrasound to calculate this distance it was necessary for the robot to ignore reflections and only accept the line of sight path of the transmitted ultrasound. Only the start time for the received ultrasound waveform was necessary for TOF measurements. In order for the micro-controller to receive the start time it was encoded as an active high TTL signal.

Piezo elements were used to detect the transmitted ultrasound signal. From laboratory measurements of the Piezo elements the maximum detectable peak voltage was 1.5 V, while the minimum was 10mV. Filtering was used since the size of the received signal made noise rejection necessary. The ultrasound waveform was centered at a frequency of 40KHz with a 1KHz bandwidth.

It was necessary for the robot to synchronize the ultrasound transmissions from the beacons. In order to synchronize the beacons a wireless beacon controller using infrared was implemented. Since the transmitted infrared signal contained a 40KHz component it was required that the infrared transmitter and ultrasound receiver be isolated from each other.

Two motors controlled by the micro-controller performed robot movement. The robot was required to move backwards, forwards, turn left and turn right. It was therefore necessary to implement at least two motor controls with variable speed and direction. The motors were required to carry the weight of the robot itself.

Since the entire project cost was to be under $400, the robot cost was required to be under $300. The excess funds of $100 were required for the beacon construction costs.

3.2.3 Beacon Requirements

The beacons were required to transmit an ultrasound signal. In order to synchronize the beacon transmission the robot controlled the transmission start time and end time for the individual beacons remotely. To determine the TOF between the robot and the beacon the micro-controller required the start time for the ultrasound transmission. The ultrasound transmission was required to traverse a distance of at least 2-3 meters and to be received by the receiver at a voltage level of at least 10 mV peak. Additionally, the ultrasound transmission was required to cover the entire operating area for the robot.

In order to perform the trialation measurements, at least 2 beacons were needed. The robot was required to know the placement of the individual beacons. Since in a practical application the number of beacons would be numerous, the cost of the beacons was required to be under $50.

Chapter 4

Design Issues

4.1 Ultrasound transmission

The accurate determination of location required the design of an ultrasound transmitter/receiver system with accurate TOF measurements. Additionally, in order to meet the distance requirements, the ultrasound transmitter needed to be powerful, while the ultrasound receiver needed to be sensitive.

The ultrasound transmitter was designed to transmit a 40KHz ultrasound signal controlled by an active high signal. In order to meet the requirements, a circuit was built which employed an oscillator and an amplification stage. The 40KHz oscillator was constructed using a crystal oscillator driving an Schmitt inverter. The oscillator produced a TTL signal, which was then controlled by the active high signal through the use of an Schmitt NAND gate. A second NAND gate replaced the inverter since they have similar operation.

The output of the NAND gate was then amplified through the use of two stages: an emitter follower, and a signal transformer. The emitter follower amplified the signal, which was then fed into a signal transformer. In order to remove the DC biasing of the signal amplifier the output of the emitter follower was coupled through a capacitor into the signal transformer. In order to drive the signal transformer the emitter follower had to be designed to supply sufficient current. Additionally, the ground of the output for the signal transformer was separated from the input ground in order to prevent ringing.

The ultrasound receiver was designed to receive an ultrasound signal with a frequency of 40KHz and amplitude of 10mV peak. The output of the ultrasound receiver was a TTL active high signal showing the start time of the received ultrasound waveform. The circuit created utilized a series of amplification stages, filter stages and a bistable multivibrator.

To remove the use of a negative voltage rail, the circuit used a 5V dc bias from a 5V rail. The amplification stages were limited by 0V and 10V rails. Several opamps were tested for use with the amplification stage, however the LM833 was chosen for its high slew rate and quick response from saturation. A simple high pass and low pass filter were used to isolate the signal, which compensated for the noise component residing mostly outside of the 40KHz band. The piezo element used performed much of the filtering since its oscillations were restricted to a band of 40KHz +/- 1kHz. The amplified signal was fed into a half wave rectifier. The rectified signal was used to drive the bistable multivibrator, which produced a 0 to 10 V signal. The bistable multivibrator was chosen due to its ability to drive the input to the MPP board. The signal was limited to 0 to 5 V through the use of the 5V rail and a diode. A current limiting resistor was used to refrain the diode from sinking the output of the opamp into the 5V rail during 10V saturation. The design of the ultrasound receiver is detailed within figure 5.2.

The design of the ultrasound transmitter was a redesign of the circuit created by Thompson [3]. Improvements were made in the amplification stage through the use of the emitter-follower and the signal transformer. Thompson utilized a 555 timer to control the on time of the transmitter. The timer was deemed to be unnecessary since the infrared controller could perform this function. The design proposed by Thompson for the ultrasound receiver was modified significantly. The use of the negative voltage rail was eliminated through the extensive use of dc biasing. Additionally, the use of the half wave rectifier significantly improved the operation of the bistable multivibrator. The filter-stage was simplified by low/high pass RC filters.

4.2 Beacon Synchronization

Several beacon synchronization techniques were proposed. The advantages and disadvantages of each of these methods were evaluated and ultimately, infrared control was chosen.

Previous beacon navigation design projects utilized a wireless RF receiver and transmitter to synchronize the beacon transmissions. RF control of beacons would involve the use of a single RF transmitter and either individual RF receivers or a single RF receiver controlling multiple beacons. Typically RF transmitters/receivers transmit serial data and require basic handshaking. Previous implementations of RF transmitters/receivers involved the use of either a decoder or a processor on the receiver side.

The use of RF was deemed to be impractical due to the cost factor along with its complexity. In order to minimize the costs of the beacons it was preferable to avoid using a significant processor in the individual beacons. Additionally the use of a single processor to control multiple beacons was found to be undesirable since the beacons would be hard wired to each other.

Another proposed solution to the problem of beacon synchronization was the use of Time Division Multiplexing (TDM) techniques in synchronizing beacon transmission. This method would involve each of the beacons transmitting during a specified time window. The implementation of TDM would consist of synchronized clocks within each beacon and the receiver. The clocks would increment a counter which would feed instantaneous time values into a comparator. Each beacon would therefore transmit during a specified time determined by the comparator.

This method was determined not to be feasible due to the synchronization problems involved with multiple clocks. For the clocks to be synchronized, they would either need to be hardwired or the individual beacons would need to synchronize upon power up. Additionally, power consumption would be greatly increased due to the beacons being on, continuously. Also, problems due to interference of the ultrasound transmissions would cause gaps in the received transmissions, which could be misinterpreted as start times for TOF.

Another proposed solution involved the use of ultrasound to signal the beacons to transmit. The beacons would then transmit their own ultrasound pulse, which would be received by the robot. Reflections from surfaces would cause the robot to detect its own signal as the TOF signal. Additionally, reflections might cause the transmitters to either transmit twice or after the wrong delay.

It was determined that the advantages of infrared transmitters made infrared the most practical solution. Infrared decoders/encoders are significantly cheaper then RF receiver/transmitter units. The typical maximum range of infrared transmission is about 100 feet while that of RF can be up to 500 meters. Since the distance between the robot and the beacons would be under a few meters the excess range of the RF would be wasted. Additionally, the extra range would be susceptible to more sources of noise. Infrared transmission requires line of sight, however this is not considered a disadvantage in this case since the ultrasound transmission required line of sight as well. The use of infrared decoders/encoders would not require the implementation of a microprocessor on the beacon.

The major disadvantage of the infrared transmission was the failure rate of the individual transmissions. It was found that the encoder/decoders would not operate consistently in ambient lighting conditions. This problem was overcome by taking multiple samples and error checking.

Infrared encoders/decoders produced by Reynolds Electronics was utilized to encode/decode the infrared transmission. The Reynolds encoder/decoders were PIC based devices suitable for remote control operation. The advantages of the Reynolds encoder/decoder pair were the latched operation of the output decoder. This operation consisted of the encoder receiving an active low pulse, which would turn on or off the output of the decoder depending on its previous state. This was advantageous because the decoder would only receive a single pulse meaning that it would either turn on at the right time or not turn on at all. This was an important factor in infrared feasibility with TOF measurements.

However, the pulsed input into the encoder introduced another problem, the transmitter would only know when the beacon was off from the input to the ultrasound receiver. If both beacons were on simultaneously the transmitter would not be able to distinguish which beacon to turn off. In order solve this problem a third infrared channel was utilized in order to reset the decoders. The reset circuit consisted of parallel Schmitt inverters driven by the third output from the decoder. During normal operation the output would be low and the beacon would operate normally. If the beacon failed to turn off the robot would use the third channel, causing the Schmitt inverters to reset the decoders.

4.3 Error checking

In order to calculate it's position the robot used the distance between itself and the beacons. These distances were calculated using the TOF of the ultrasound pulse from the beacon to the robot. Infrared transmissions travel at the speed of light and are therefore assumed to be instantaneous with respect to ultrasound. It was found that the infrared transmission only added a fixed delay that was independent of the distance between the infrared transmitter and the infrared receiver.

Since the TOF measurements involved heavily upon the successful transmission of an infrared pulse and the successful reception of the ultrasound pulse, error checking became very important. The infrared was found to be inconsistent in ambient light and the ultrasound reflections tended to interfere with operation. It was found that the use of error checking was necessary to ensure successful operation.

The cases in which a TOF measurement was discarded consisted of when the transmitted pulse did not arrive at the ultrasound receiver, when the received ultrasound pulse was not correctly received, when noise was received on the ultrasound receiver creating an imaginary pulse and to correct problems incurred through reflections. An additional variable delay was found to be present with the infrared transmission within harsh lighting conditions.

TOF measurements under the delay time of the infrared transmission were discarded along with TOF measurements beyond the range of the robot. Additionally, a maximum waiting time was implemented in cases of the infrared transmission not arriving at the beacon. Also, several TOF measurements were taken and the lowest measurement was kept. This allowed for the discarding of the variable delay sometimes observed in the infrared transmission.

Chapter 5

Hardware Design

The hardware design for the project consisted of the construction of the robot and the two beacons. The robot design incorporated an ultrasound receiver, an infrared transmitter, a motor controller, a microprocessor, and the motors mounted on the frame/chassis. Additionally, a battery pack and a LCD-screen were added to the robot. The beacon design consisted of an infrared receiver and an ultrasound transmitter. Power was supplied to the beacons through the use of an AC/DC power supply.

The design of the ultrasound receiver and transmitter are loosely derived from the previous work of Thompson [3]. Additionally, the design of the infrared transmitter and receiver was based from the published Reynolds [4] designs. Finally, the motor controller board was based on the work of Hiscocks [8].

5.1 Robot Construction

5.1.1 Ultrasound Receiver

The purpose of the ultrasound receiver was to amplify the received ultrasound waveform and produce an active high TTL signal. The implementation of the ultrasound receiver involved the amplification and filtering of the voltage signal produced by the ultrasound transducers. The transducers were Piezo elements, which produced a 40KHz sinusoidal voltage of 10mV peak. In order to receive the ultrasound pulse with identical intensity from all directions,

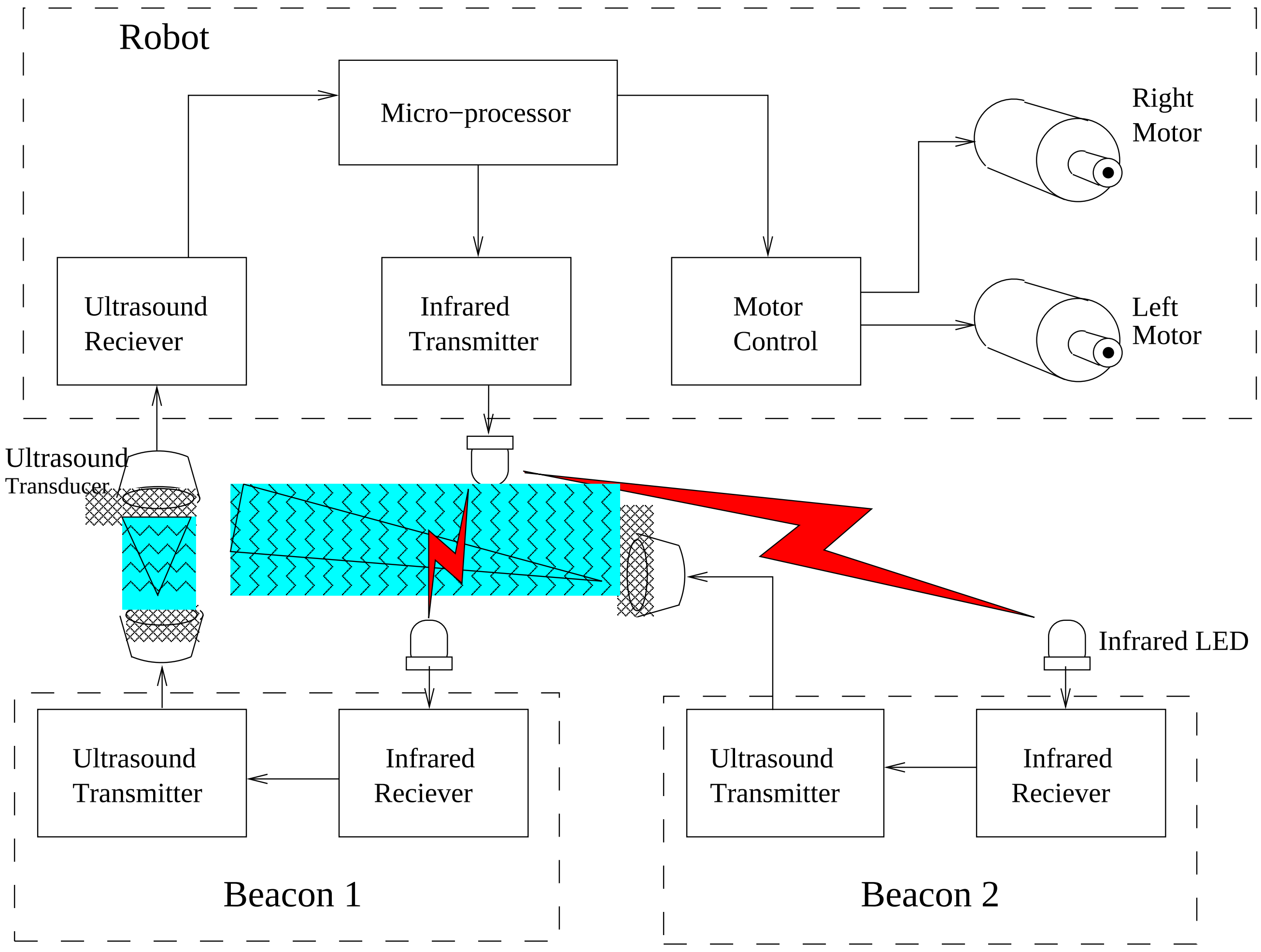

Figure 5.1: Block Diagram of Hardware

eight ultrasound transducers were used. These transducers were mounted a few inches above the chassis of the robot within the middle of the frame. This was necessary in order to provide TOF measurements relative to the center of the robot. Additionally, grouping the transducers within the center of the robot allowed for increased coverage.

The received signal from the Piezo element was then filtered and amplified by the receiver. The amplification was accomplished through 3 operational amplifiers. These amplifiers were configured as negative feedback amplifiers with a gain of 10. Since the input to the receiver from the transducers could vary from 10mV to 1V the amplifiers operated within the saturation region the majority of the time. Also, since the amplified signal was at 40KHz, the slew rate for the opamps was critical. It was found that the LM833 had sufficient slew rate and recovered from saturation quickly enough to be suitable for this application.

Since the Piezo elements themselves accomplished much of the filtering, a simple RC filter was implemented. The use of variable resistors allowed for an adjustable stop-band.

The amplified waveform was converted into a TTL signal through the use of a rectifier and a bistable multivibrator. The output from the amplification/filtering stage consisted of a square wave with amplitude equal to the positive and negative rails. This waveform was rectified through the use of a capacitor and a diode. A parallel capacitor was necessary for the implementation in order to drain the capacitor during the off state. The output from the rectifier was then fed into a multivibrator in order to produce an on/off signal. A variable resistor set the threshold voltage for the multivibrator.

In order to avoid the use of a negative rail the opamps were operated from 0 and 10 volt rails along with a DC bias of 5V for the input signals. In order to prevent the output of the multivibrator from passing 5V a diode was placed from the output to the 5V biasing rail. In order to prevent the output of the multivibrator from sinking into the 5V rail a resistor was placed on the output. The schematic for this circuit can be seen in 5.2.

Note, the ultrasound transducers used were obtained from Sayal Electronics. These ultrasound transducers were not labled and therefor a specification sheet could not be obtained.

5.1.2 Infrared Transmitter

The infrared transmitter consisted of an infrared encoder driving a series of infrared LEDs. The infrared encoder was obtained from Reynolds electronics and consisted of a PIC with three inputs, a 4 MHz oscillator, voltage rails, and an output used to drive the infrared transmitting LED. Since the robot could be facing any direction the output of the PIC was required to drive four separately facing infrared LED's.

Since the current draw from the encoder was insufficient to drive four LED's a series of Schmitt inverters and transistor Darlington pairs were used to drive the LED's. The output of the encoder drove a single inverter, which in turn, drove two parallel inverters. These two inverters provided biasing current for four sets of Darlington pairs. These Darlington pairs would sink the current through the infrared LED's driving them with the unregulated battery voltage.

The inputs for the encoder were three active low input pins. In order for the MPP board to drive these inputs as active high signals a series of three Schmitt inverters were used. The schematic for this circuit can be seen in 5.3.

5.1.3 Motor Control

The motor controller was designed from the design of the eebot motor controller. This design consisted of the use of the L293D, which consisted of an H-Bridge with output limiting diodes. The input into the L293D consisted of an enable and two direction inputs for each motor. An inverter was used to drive the second direction input so that the two directions could be driven from a single input. The L293D contained required two voltages for operation, chip voltage and motor power voltage. A 5V regulator produced the chip voltage while the motor voltage was taken from an L317 variable voltage regulator. This allowed for the motor voltage to be limited depending on the motors used. The schematic for this circuit can be seen in 5.4.

5.1.4 MPP board

The MPP board was utilized to control the various aspects of the robot. Port A TIC1 input was used to retrieve the output from the ultrasound transmitter. TIC1 was used for this purpose in case greater accuracy is required in the future for TOF measurements and the timer is required to be used. The motor controller was driven by four outputs from the output port of the MPP board. These outputs were enable right motor, right motor direction, enable left motor, and left motor direction. In order to drive the infrared transmitter three more outputs from the output port were used.

5.2 Beacon construction

5.2.1 Ultrasound transmitter

The ultrasound transmitter within the beacon was used to transmit the ultrasound pulse to the ultrasound receiver within the robot. The transmitter was controlled by an active high signal from the infrared receiver and produced a 40KHz sinusoidal waveform used to drive the ultrasound transducers. The 40KHz waveform was created through the use of a 40KHz oscillator driving a Schmitt NAND inverter. A second Schmitt NAND inverter controlled the output of the oscillator. This output was then driven into an emitter follower amplification stage. The emitter follower was used to create +/- 5V signal, which was used to drive a signal transformer. In order to prevent DC biasing of the transformer a capacitor was used to couple the output of the emitter follower to the transformer.

The signal transformer was chosen based on the gain and the input resistance. An input resistance of 8 ohms along with a turn ratio of 8:1000 was found to be sufficient. The output produced by the signal transformer was found to be 30 Volts peak sinusoidal waveform. This output was sufficient to drive the ultrasound transducers. It should be noted that the use of the transformer adds a small delay in the rise time of the output waveform. This delay can be attributed to the flux build-up of the transformer before it reaches peak performance. The schematic for this circuit can be seen in 5.6.

5.2.2 Infrared Receiver

The infrared receiver consisted of a PIC programmed by Reynolds Electronics to act as an infrared decoder. The Reynolds decoder accepted the input from an infrared photo sensor which was itself biased by 5V. The received infrared was then decoded into three separate outputs. Two of these outputs were required to control two separate beacons. These outputs were the active high input necessary for the ultrasound transmitters to turn on.

Additionally the third output of the decoder was used to drive the input of six parallel Schmitt inverters. These Schmitt inverters were used to provide the source voltage for the infrared decoders. This allowed for the third input to reset the PIC, turning off all outputs. Each of the two beacons utilized the reset channel along with their own channel for ultrasound transmission. Since there were two beacons implemented a total of three infrared channels were required. The schematic for this circuit can be seen in 5.7.

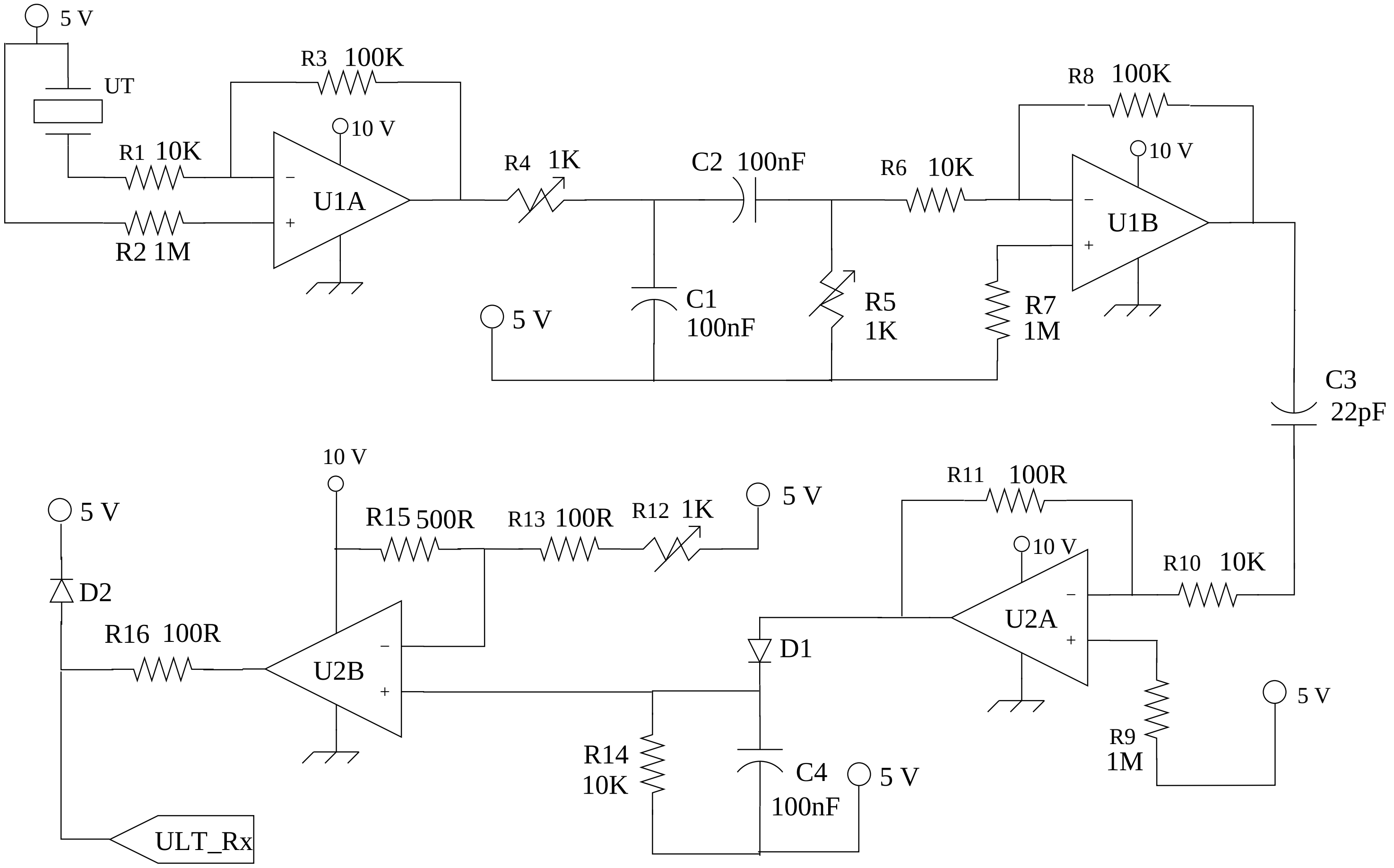

Figure 5.2: Ultrasound Receiver Hardware

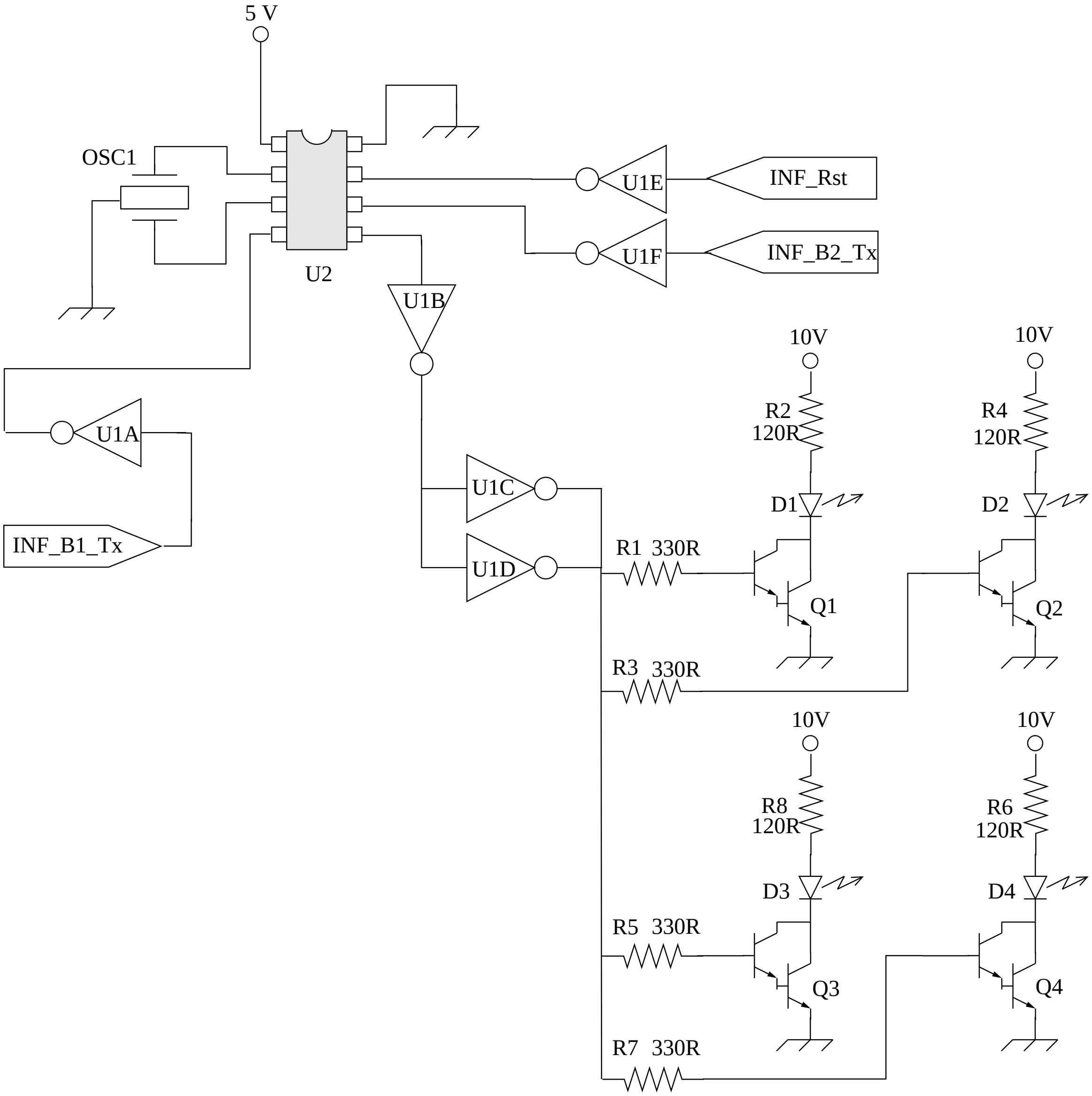

Figure 5.3: Infrared Transmitter Hardware

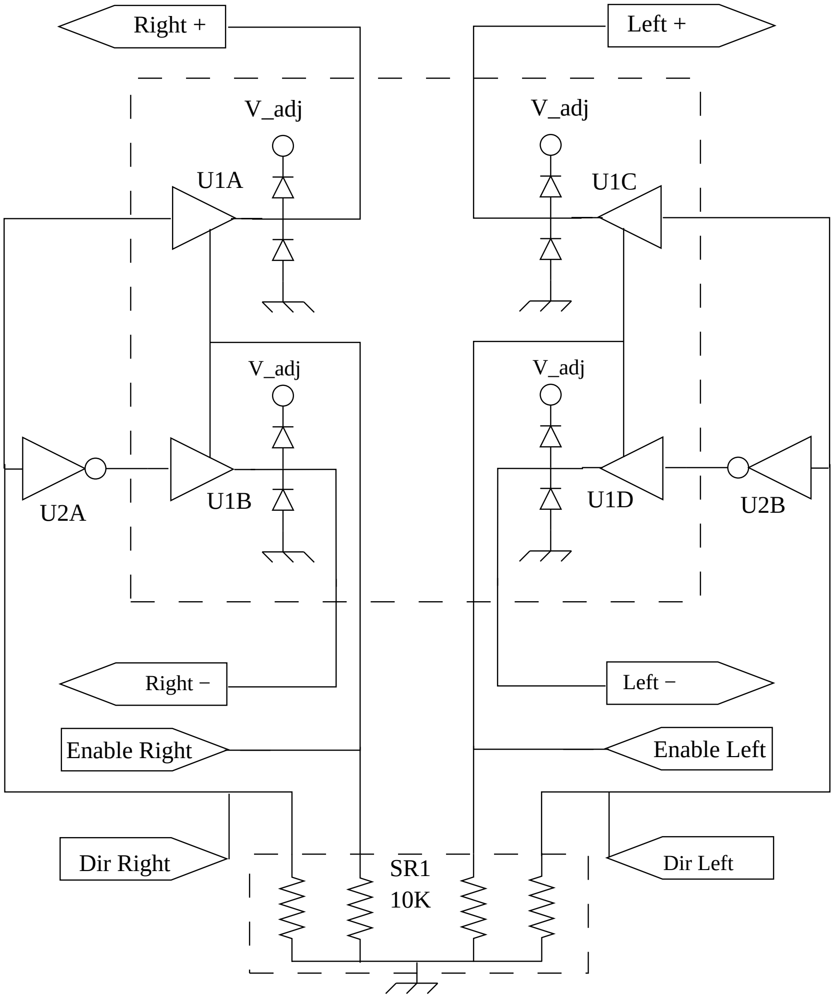

Figure 5.4: Motor Controller Hardware

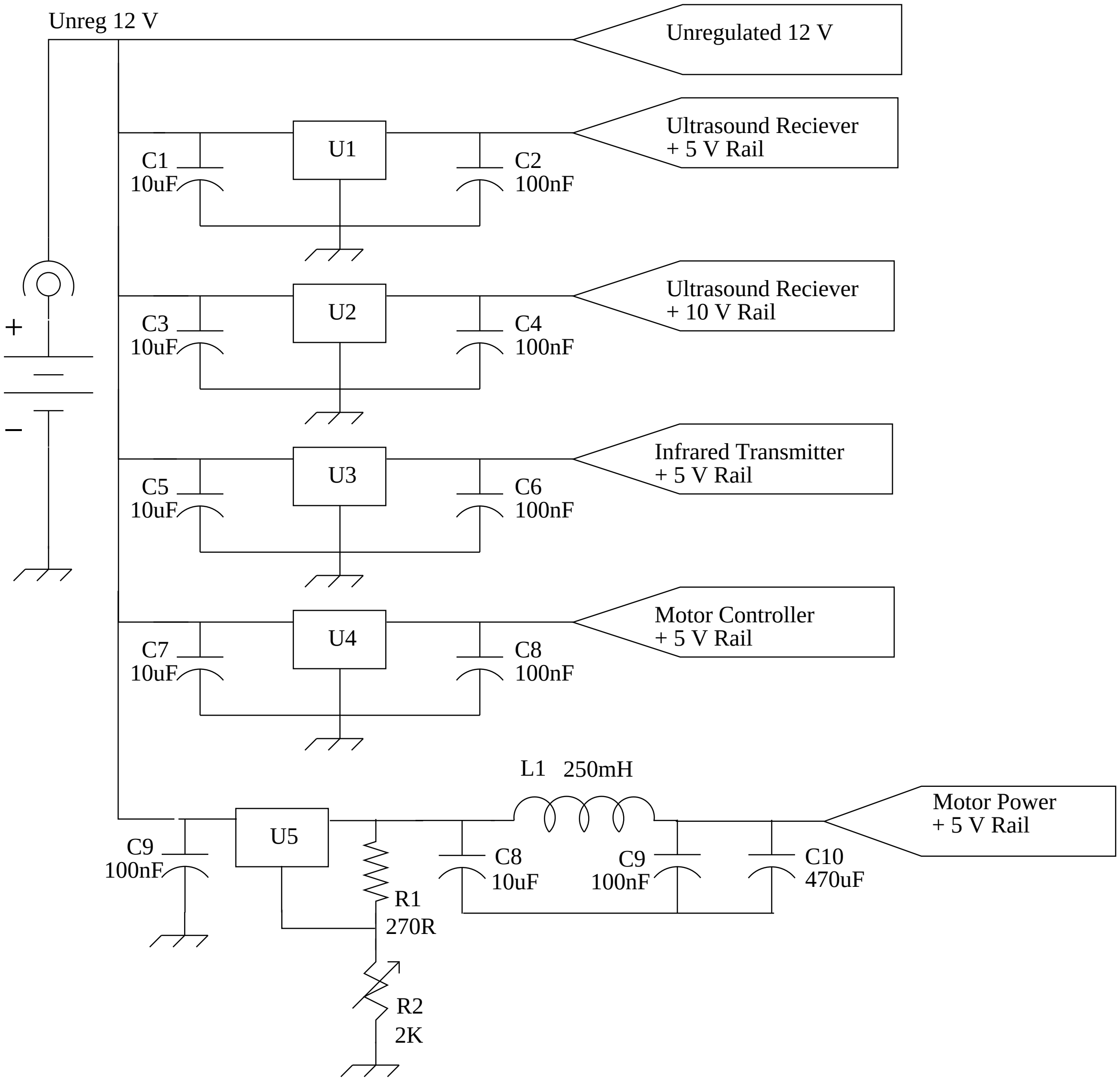

Figure 5.5: Power Supply Hardware

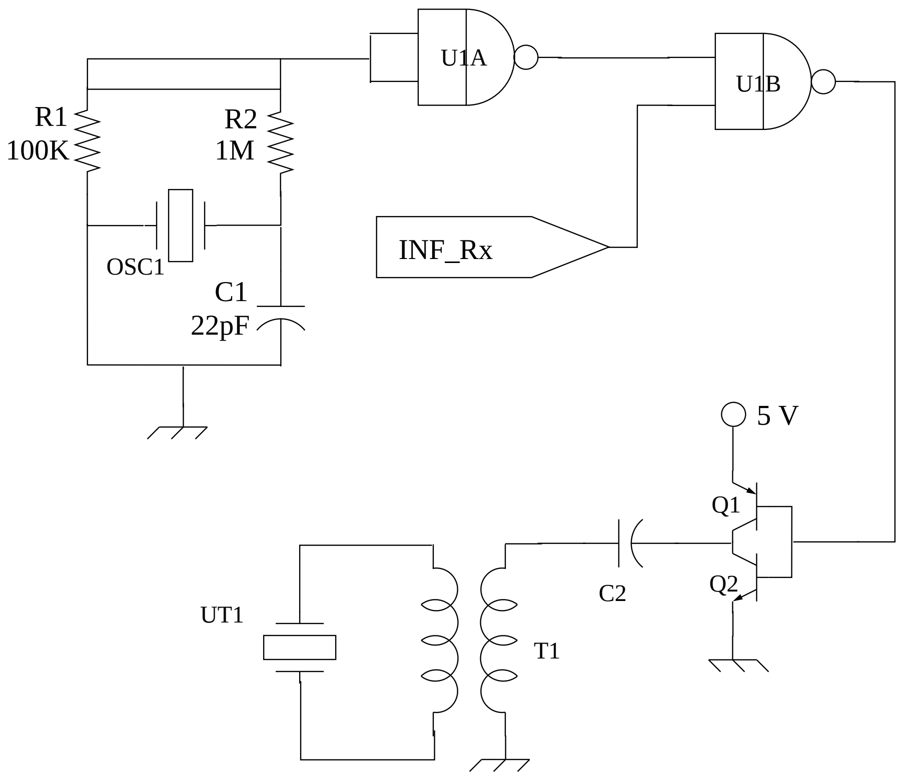

Figure 5.6: Ultrasound Transmitter Hardware

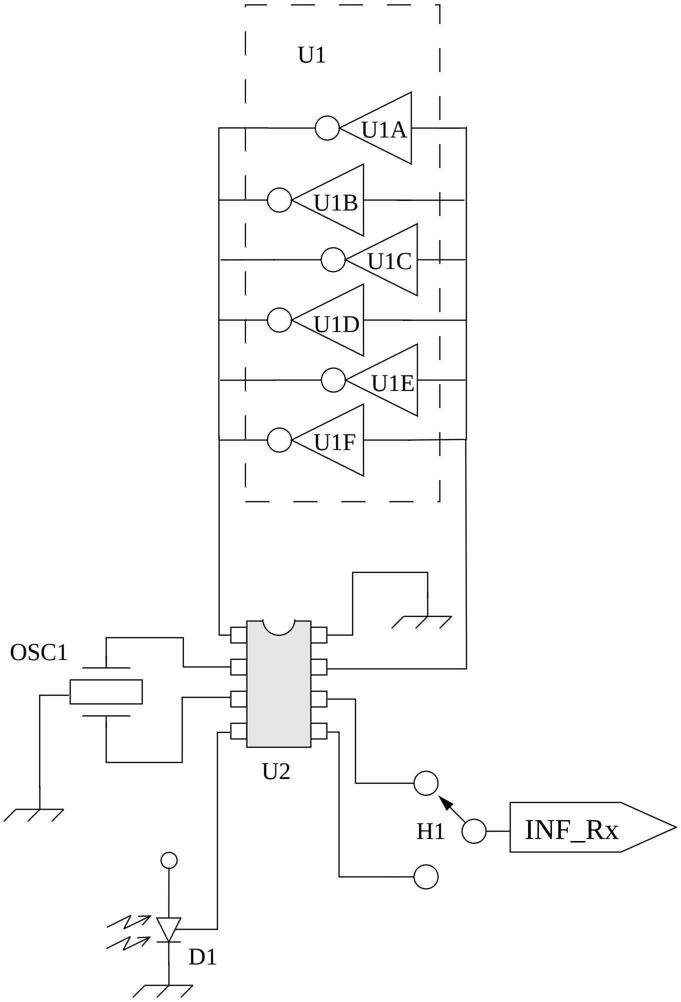

Figure 5.7: Infrared Receiver Hardware

Chapter 6

Software Design

The software design consisted of the assembly instructions necessary for the MPP board to operate the robot and synchronize the beacons. The code began with a routine in which the individual distances between the robot and each of the two beacons were found. Following this the MPP board would perform the necessary triangulation calculations with these two distances to produce Cartesian coordinates. The Cartesian coordinates were then used to control the robot behavior. The main algorithm for the software can be see in 6.1.

6.1 TOF Measurements

Routines for determining the distance utilized the TOF measurement between the transmission time of the infrared transmitter and the receive time of the ultrasound transmission. A routine was created in which the MPP board would transmit the infrared pulse to turn on the beacon. The program would then enter a loop where the TIC1 would be continuously checked an a register was continuously incremented. Once the TIC1 input was detected as high the routine would exit the loop and the counter within the register would represent the TOF measurement.

A routine was developed in order to ignore incorrect TOF measurements. For the case in which the infrared transmission failed to turn on the beacon the routine would reinitialize if the register in the above loop reached a maximum value. Additionally, TOF measurements under the minimum delay imposed by the infrared or beyond the maximum range of the robot would cause the routine to re-initialize. Finally, multiple TOF measurements were taken and the smallest value was kept. This allowed for the routine to ignore variable delay introduced by the infrared transmission during harsh lighting conditions.

In order to turn of the beacons either another strobe could be sent to that infrared channel or the reset channel could be used. It was found that the decoder recovered slowly from the reset so it was preferable to use the transmission channel first. If resetting the output from the transmission channel failed the routine would utilize the third channel. The routine could only use the input to TIC1 to determine if the beacons were off. Therefore, a time delay was introduced between reset attempts. The main algorithm for the determination of distance can be seen in 6.2.

6.2 Distance Calculations

The Cartesian coordinates were derived from the trialation calculations from the two distances from the beacons to the robot. First, the TOF measurement was converted into a distance measurement. Since the accuracy of the location was required to be within +/- 1 cm the distance was represented by an integer in centimeters. The conversion between the TOF measurement to distance measurements are shown below:

Distance = [TOF - (Infrared Delay)] * (speed of sound)

The triangulation calculations were performed with the use of the floating point math package for the 6811. The general operation for the floating point calculations were based upon the trialation calculations shown in the theory section.

6.3 Motor Control

The motors were controlled by four outputs from the output port. The required driving signals for the motors were right motor enable, left motor enable, right motor direction, and left motor direction. Through the use of pulse width modulation, the speed of the individual motors were controlled.

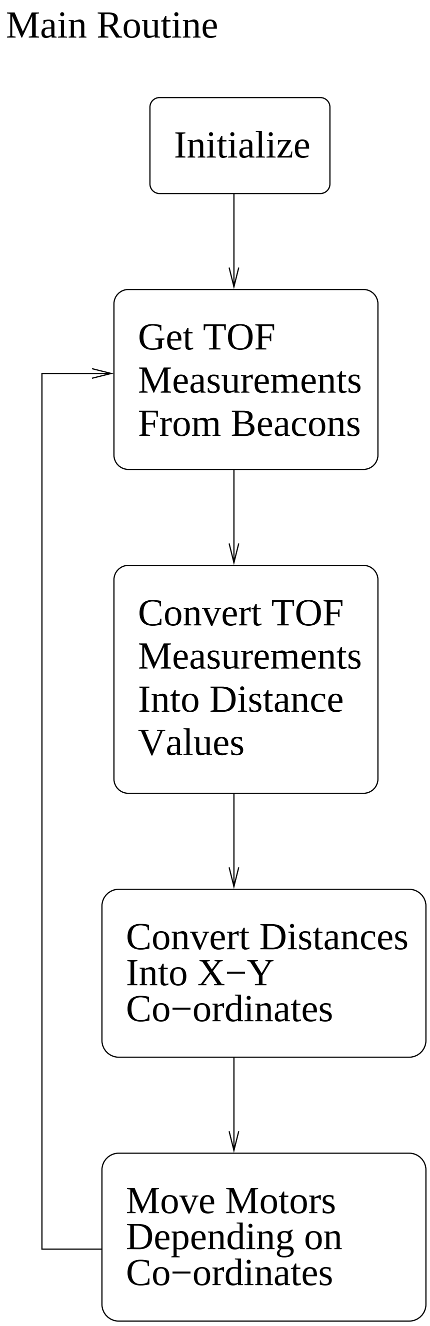

Figure 6.1: Main Software Routine

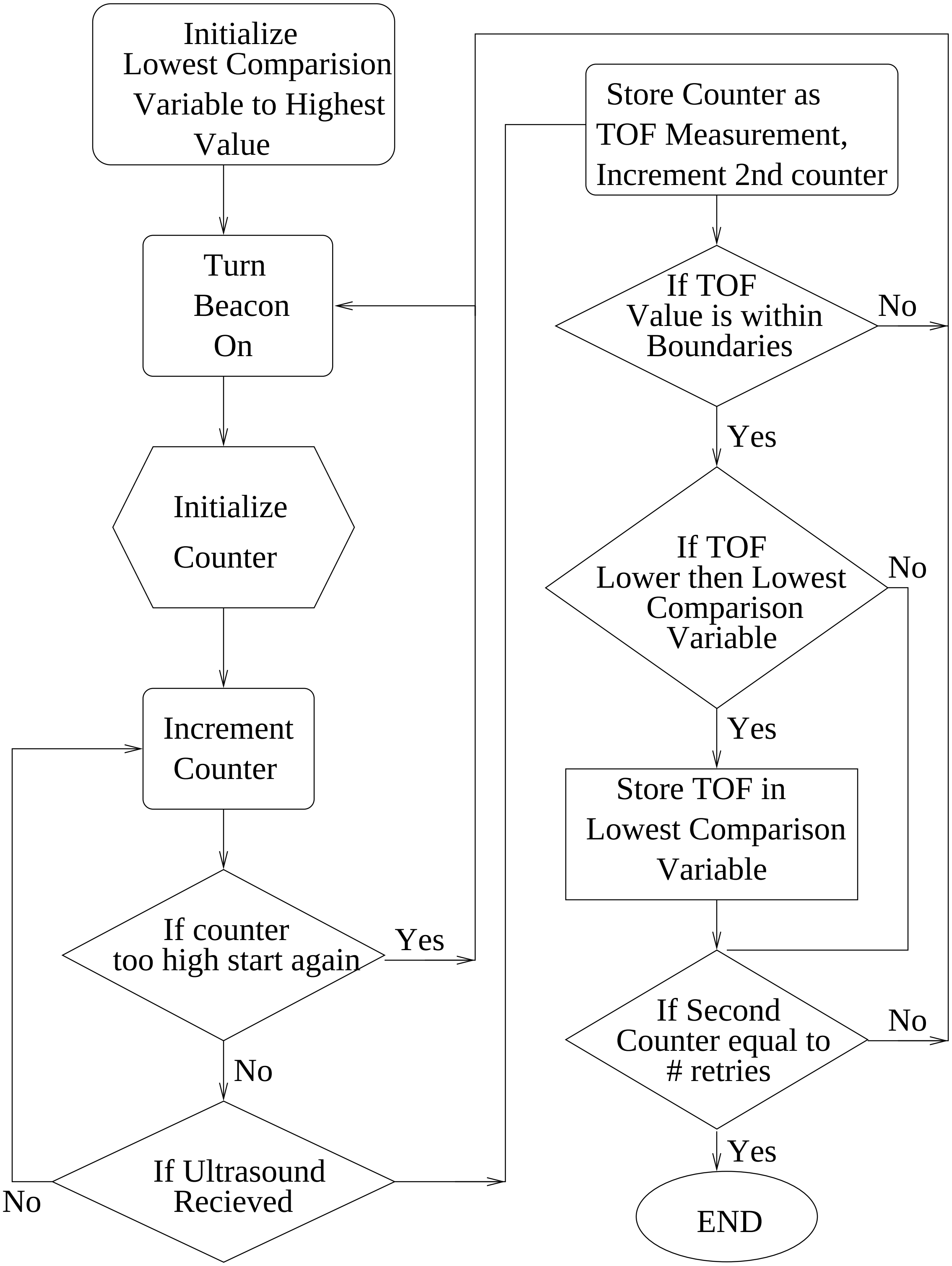

Figure 6.2: Software Routine to Obtain Distance

Chapter 7

Conclusion

7.1 Observed Operation

The robot was constructed as per the hardware and software specifications. Testing of the robot found that location coordinates error was 2.34cm which was within the boundaries specified. Additional testing found the error rate of misoperation to be adjustable to within one out of 5 errors with a refresh rate within 2 seconds. Since the number of distance measurements before calculations is adjustable within the software these errors could be reduced by sacrificing execution time.

Operation of the ultrasound transducer was found to be reliable within distances of 5m. Additionally, the infrared receiver/transmitter was capable of transmitting a great distance (at least 20m) however, lighting conditions affected the reliability significantly.

The final operation of the robot consisted of it moving within an imaginary box defined within the software. This algorithm is detailed within the software section and sufficiently tested the functionality of the robot.

7.2 Discussion

The robot constructed was found to be reliable if the number of distance retries was kept above 5. This was necessary since the infrared transmitter/receiver showed a small variable delay in transmission. The ultrasound receiver was found to be susceptible to noise, however this was reduced due to the use of metal plating throughout the robot construction. Additionally, the infrared receiver was susceptible to noise from the ultrasound transmitter if the cables were in close proximity to each other. Besides these small issues, the robot functioned satisfactorily within the specification set forth.

One of the challenges within this design project was developing an ultrasound transmitter/receiver board which was not susceptible to noise. This required the development of multiple board revisions and the liberal use of capacitors. Additionally, integration of the separate pieces of this project was a nightmare because of the initial noise problems.

This project met the initial design objectives. Additionally, this project has shown that the use of infrared is a viable option in beacon synchronization. Throughout the course of my research there were not many instances of infrared being used for beacon communications. The majority of applications involved more complex radio transmissions. The biggest advantage of the infrared system was that it did not require an intelligent controller on the beacon side.

7.3 Suggested Improvements

During the completion of this project many possible improvements to future designs became evident. The use of infrared in beacon control was found to be effective, however it would be interesting to observe the performance of alternative methods. It would be worth while to explore Synchronization methods involving the use of time division multiplexing or even ultrasound encoding/decoding.

Other improvements in future designs could involve increasing the number of beacons used. With a larger number of beacons, additional error checking could be implemented, as well as positioning within three-space. Another advantage would be the ability to navigate the robot along long corridors and around corners. Since the robot requires at least two beacons to determine location, beacons could be distributed around obstacles which would normally block the ultrasound signal. As the robot navigates around obstacles new beacons would become visible while previously used beacons would disappear. This would require the robot to be able to acquire new beacon reference points and discard unused reference points. New beacon positions could be either pre-stored within memory along with the beacon ID or the position could be acquired through trialation. This could allow the robot to move around corners in hallways and perhaps navigate throughout a building.

Definitely, future work should be done on the use of position measurements to control the movement of the robot. Through the use of vector algebra the robot should eventually be able to move to specific points within its two space.

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Appendix A

Parts List

Part	**Part Number**	**Description**
R1	100K	Resistor
R2	1M	Resistor
C1	22pF	Capacitor
C2	1uF	Capacitor
Q1	2N3904	Capacitor
Q2	2N3906	Capacitor
OSC1	XTAL	40KHz oscillator
U1	74HC132	Schmitt inverting NAND gate
UT1	From: Sayal	Ultrasound Transducer

Table A.1: Ultrasound Transmitter Hardware

Part	**Part Number**	**Description**
R1	10K	Resistor
R2	1M	Resistor
R3	100K	Resistor
R4	1K pot	Resistor
R5	1K pot	Resistor
R6	10K	Resistor
R7	1M	Resistor
R8	100K	Resistor
R9	1M	Resistor
R10	10K	Resistor
R11	100R	Resistor
R12	1K pot	Resistor
R13	100R	Resistor
R14	10K	Resistor
R15	500R	Resistor
R16	100R	Resistor
C1	100nF	Capacitor
C2	100nF	Capacitor
C3	22pF	Capacitor
C4	100nF	Capacitor
D1	1N4004	Diode
D2	1N4004	Diode
U1	LM833	Audio grade Opamp
UT	From: Sayal	Ultrasound Transducer

Table A.2: Ultrasound Receiver Hardware

Part	Part Number	Description
R1	330R	Resistor
R2	120R	Resistor
R3	330R	Resistor
R4	120R	Resistor
R5	330R	Resistor
R6	120R	Resistor
R7	330R	Resistor
R8	120R	Resistor
D1	OELEL1L2	IR LED 200mW
D2	OELEL1L2	IR LED 200mW
D3	OELEL1L2	IR LED 200mW
D4	OELEL1L2	IR LED 200mW
U1	74HC14	Hex Schmitt Inverter
U2	tiny-IR Tx	Reynolds IR encoder
Q1	ZTX603	Darlington NPN transistor
Q2	ZTX603	Darlington NPN transistor
Q3	ZTX603	Darlington NPN transistor
Q4	ZTX603	Darlington NPN transistor
OSC1	ZIT	4MHz oscillator

Table A.3: Infrared Transmitter Hardware

Part	Part Number	Description
D1	From: Supreme	IR optical receiver (40KHz)
U1	74HC14	Hex Schmitt Inverter
U2	tiny-IR Rx	Reynolds IR decoder
OSC1	ZIT	4MHz oscillator

Table A.4: Infrared Receiver Hardware

Part	Part Number	Description
SR1	10K	SIP resistor package
U1	L293D	H-Bridge with limiting diodes
U2	74HC14	Hex Schmitt Inverter

Table A.5: Motor Controller Hardware

Part	**Part Number**	**Description**
C1	10uF	Capacitor
C2	100nF	Capacitor
C3	10uF	Capacitor
C4	100nF	Capacitor
C5	10uF	Capacitor
C6	100nF	Capacitor
C7	10uF	Capacitor
C8	100nF	Capacitor
C9	100nF	Capacitor
C10	470uF	Capacitor
U1	7805	5 Volt regulator
U2	7810	10 Volt regulator
U3	7805	5 Volt regulator
U4	7805	5 Volt regulator
U5	LM317	Adjustable Voltage regulator
L1	250mH	Inductor

Table A.6: Power Supply Hardware

Appendix B

Code Listing

Appendix C

Product Data Sheets

VITA

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