Microprocessor II Final Project:
Hardware Preliminary Design Report

Ladder 42

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Abstract

The problem statement describes the need for a fully autonomous robot to compete head-to-head in a race to locate and extinguish a burning candle. The robot must be autonomous in the sense that it must be able to detect the beginning of a round, be able to locate a candle while avoiding obstacles, and be able to extinguish the candle within 30 seconds of it arriving at the candles location. The initial design that has been conceived is comprised of two infrared cameras, a full color camera, and a GSM module capable of communicating over T-Mobile's cellular networks. Other less crucial sensors are also being utilized such as a digital compass for general orientation assistance, servo motors to move the cameras, passive ‘whiskers’ for physical object and wall detection, LED - photodetector pairs for use on encoders in the wheels, and a color sensor for detecting the white circle around the candle. The body/frame of the robot is going to be a custom designed and built PCB that will allow us to use much smaller and more advanced SMD parts such as the more powerful PIC18F97J94 processor while also keeping the overall size and weight of the robot down. Our primary goal is to design a robot that is as small and fast as possible while using reliable sensors that cannot accidentally or maliciously be interfered with by an enemy robot.

Scope of Project

The objective of this project is to design and produce a fully autonomous robot that is able to distinguish audio tones, navigate a maze, and extinguish a burning candle. The robot must be based around a microprocessor from the PIC18F family and be able to fit entirely within a 6”x6”x6” box. Our personal goals obviously include these major requirements as well as more technically complex challenges. In order to differentiate audio tones our robot will use an electret mic and amplifier that is being processed by a software FFT subroutine on the PIC. Once the robot has successfully recognized the signal to begin it must navigate to the candle successfully. It will take advantage of its high accuracy FFT reading for hemisphere location and use its three cameras to detect and avoid obstacles. If an obstacle is missed by the cameras the passive whiskers surrounding the bot will be activated notifying the robot that it has collided with an object. Once the robot has located the candle it will use its onboard GSM module to call or text one of our cell phones to notify us of the candle’s location so we may extinguish the flame.

To tackle all the individual tasks we delegate sub-phases based on interest and past experience. This allows us to be more efficient in our progress as well create a complete and concise list of objectives that still need to be met. Our Sub-phases can be divided up into categories as seen on the next page.

- Power supply

  The power supply must be designed to run on a battery that is able to supply enough voltage to power all peripherals while also lasting long enough to power a robot throughout the entire competition. The person responsible for the power supply circuitry will be required to source a battery and design a circuit capable of providing all voltage levels required by the various components. It is important that the power supply does not brown out because of the motors or any other peripherals. The GSM module may benefit from having its own battery and this decision would be up to the person assigned to the power supply.

- GSM cellular connectivity

  Our robot takes advantage of T-Mobile's 2G cellular network to communicate with our cell phones through texting or calling to inform us when it locates a candle and of the candles location. The person responsible for the GSM connectivity will be responsible for interfacing with the module through UART and writing all necessary software to communicate with the module. It will also be the responsibility of this person to get the robot connected to the GSM network though T-Mobile and get a phone number assigned to our robot.

- IR cameras

  The person responsible for the IR cameras will be required to source the cameras from 1st generation Nintendo Wii remotes. Support circuitry will need to be designed and constructed so that the IR cameras will function externally from the Nintendo Wii remotes. The person responsible for this will also be responsible for writing and calibrating the software that interprets the feed from the IR sensors to produce a crude 3D model of the environment directly in front of the robot. The resources must be made available to interface with this 3D model from the central control algorithm to determine motor control and object avoidance.

- Full color camera

  The full color camera, or Pixy, will serve the purpose of overlaying data on the crude 3D model created by the IR cameras. More specifically, the person assigned to interface with the Pixy will have to make slight modifications to the stock firmware so as provide a 3D model of the visible ground plane to the central control algorithm. Software will also need to be written for the PIC to interface with the Pixy and overlay the data from the Pixy and the 3D model from the IR cameras.

- Audio interface

    This is the task of designing the circuit to amplify and filter the audio from an electret mic so it can be fed into an analog input on the PIC processor. This task also includes interpreting the incoming audio using an FFT algorithm to determine the dominant frequency so as to detect the fire alarms.

- Motor drive

    The motor drives require the design and construction of 2 full H-bridge circuits as well as the design and construction of encoder circuits to read the encoders present on our wheels. Software must also be constructed to interface with the encoder circuits and to control the speed and direction of the motors.

- Digital Compass

    One of the simpler devices is a digital compass that allows us to retrieve our absolution direction with high precision and nearly as frequently as we require. It is required that someone design the support circuitry for the digital compass module while also writing the software to interface with the compass and make the value available to the central control algorithm.

- Passive whiskers

    The person responsible for the passive whiskers will need to create software and circuitry that triggers an interrupt when one of the whiskers is in physical contact with a surface. This person will also be responsible for sourcing all the mechanical components necessary to build the whiskers as well as determining the location and number of whiskers around the perimeter of the robot.

- PCB layout

    This task is better kept as a team task because of the importance and permanence of design decisions. The team will be required to design a board that will act as a mount and frame for all physical components while also safely distributing all the signal and I/O lines in and out of the PIC processor. Care needs to be taken in regards to layout to make sure that sensitive components are not experiencing interference. Because the PCB is also acting as the frame of the robot care needs to be taken in regards to the motor mounts, camera mounts, etc. Any custom made footprints will need to be verified by both members before a board can be ordered.

- Central Algorithm

  The central algorithm is the control flow of the robot to determine its route to the candle. Because of the complexity and significance of this task, both team members will be required to contribute heavily in order to produce the fastest and most accurate algorithm. This algorithm must take advantage of all sensors and outputs it has available in order to succeed. Once the team is feeling confident with their algorithm, it would be beneficial to consult Dr. Lockwood for any recommendations or insight into more complex or reliable artificial intelligence techniques.

Plan

Technical challenges

Some of the technical challenges we anticipate encountering are interfacing with all of the sensors and reading them in a quick enough manor, routing the PCB board effectively, the image processing, the motor driving algorithm, and managing all of the interrupts.

Interfacing with all of the different sensors in and of itself should not be an issue, I2C, UART, and SPI are well documented protocols as well as having PIC libraries to handle it all. The main challenge anticipated is pulling all of the appropriate sensor data quick enough and acting on that information in a quick and logical manner. We will have to choose when we have to update specific sensor. in order to be able to update everything in one millisecond, we must have our main loop execute within 16,000 instruction cycles.

$$\frac{4}{64{,}000{,}000\ \mathrm{Hz}} * X \ \text{instructions} = 0.001\,\mathrm{s}$$

$X = 16{,}000$ [illegible]

While this sounds like a lot of cycles, with all of the different sensors, communication, along with interrupt routines and overhead, this will become a possible constraint that must be kept in mind while writing the software.

Routing the PCB completely could be a problem due to the amount of sensors we have on the board as well as adhering to communication line best practices. While we won't be involved in very high speed data transfer, with this many communication lines as well as high current power traces, crosstalk as well as routing space could become an issue very quickly if this is not kept in mind. We also plan on keeping all SMD components on the bottom side of the board in order to only have to order one stencil to keep costs low. This constrains some routing options, but with vias, smart pin assignments, smart component layouts, and smart data path routing, these problems won’t pose too large of an issue.

The image processing will be an important component of our robot. This will be the main way it detects objects, walls, and the candle. The plan as of now is to use the Pixy to detect the floor and the walls, giving us a rough idea of the terrain.
The Pixy has an on board dual core, 204 MHz NXP processor that handles most of the image processing for us. We will need to modify the existing firmware on the chip to meet our specific needs. This process is well documented as well as having a large repository of open source processing programs.

On top of the Pixy data, we will use the two wii-mote cameras with IR filters and an IR LED to detect nearby objects. The wii-motes have on board processing which send out the x,y coordinates, intensity, and size of the four largest IR light sources in the camera’s field of view. We will then use this data as well as some trigonometry to interpolate the location of the four brightest (and hopefully nearest) objects for predictive object detection. If either this method or the Pixy fails to detect an approaching object however, we will have mechanical feelers to tell us that we are about to hit an object. These will be our backups to predictively mapping where we should be driving.

Sensors

Pixy

This sensor is a very powerful image processing solution with a lot of online support and customization options. It also has a long development history, coming out of Carnegie Mellon University about eight years ago. Since then, it was successfully funded on Kickstarter with over 250,000 $ for development and mass production. Now it is under heavy development and has a large usage base in the electronics community. With a beefy 240 MHz dual core processor to handle the image processing, this will be a great solution for viewing the outside world.

IR Cameras

The Wii camera is a beautiful thing. It has built in circuitry to detect the four brightest spots that it sees, record the x-y coordinates, intensity, and size and send that data on request over I2C. Coupled with an IR filter and an IR LED, using two Wii cameras separated by a known distance and at a known angle, we can easily calculate the distance to the four brightest objects, which should be obstacles in our way or the candle. The intensity of the IR LED will need to be calibrated to give optimal object detection, but since we will also have the Pixy and the mechanical feelers, the critical use of these cameras will be the detection of the candle.

Fona GSM Module

With the option to have the robot call or text us to have us put out the fire, this simplifies the extinguishing significantly. Instead of having a complicated arm or a potentially dangerous water extinguishing unit, we can just put it out with our fingers. With an extensive library, documentation, and code examples on Adafruit along with successful texts commanded over a serial port on a PC, this will be a great resource.

Color Sensor

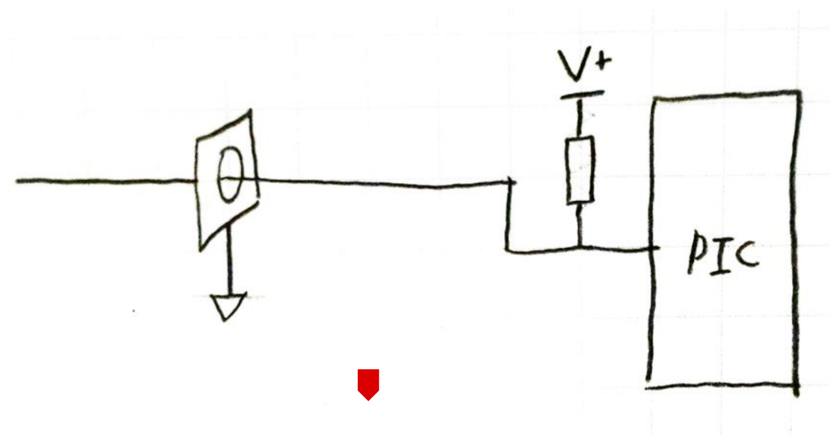
the TCS34725FN color sensor provides highly accurate color data as well as white light information over I2C. For the simple task of detecting a circle on the ground that is in contrast with the surrounding floor, this will be more than enough. The reason we went for this type of sensor instead of a simple reflectivity sensor was because the final floor reflectivity and color is not definite, so this will give us a good amount of flexibility.

Compass Sensor

For additional orientation sensing, we will be incorporating the HMC5883L three axis compass. This IC has a heading accuracy of two degrees at the worst. This gives us something to check against and bolster our positioning algorithms. For only three dollars, this is a great data point to check against.

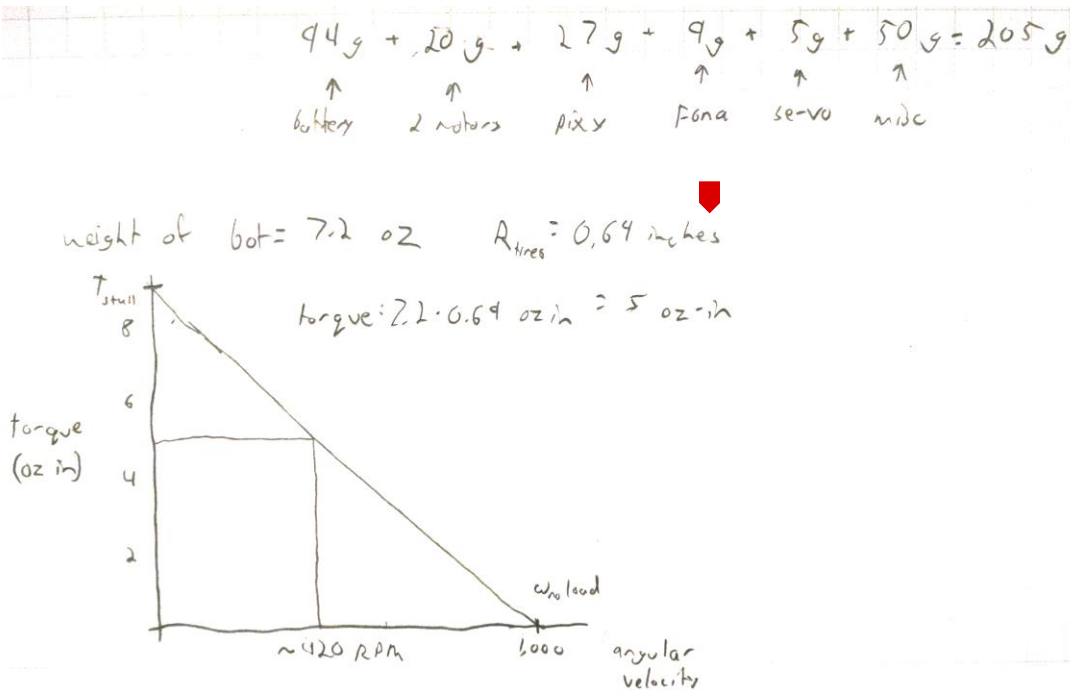
Mechanical Feelers

As a last resort, we will have multiple mechanical feelers sticking out in all directions to detect impending collisions. These feelers consist of a rigid but deformable conductive wire pulled high hooked up to an interrupt input pin sticking through an eyelet that is connected to ground. If the feeler gets hit in any direction, this will cause an interrupt on the PIC, allowing it to react before colliding with the object. This is a simple and effective last resort to avoiding collisions.



Motor Selection

With such a mechanically simple design, we only need two DC motors for basic forward, reverse, and turning. We then utilize ball casters on the front and back to stabilize the robot. Our robot will also be relatively light as well as small, meaning we don't need too much gear reduction to get the requisite amount of torque. Based on the Pololu specifications and the estimated weight of our vehicle, the following torque-speed graph was made. Our motors are more than capable of moving our robot from rest.



With further calculations based on a linear current draw from stall to free running, we will pull a max of one amp from each motor on startup. This will require a battery that can safely handle higher current draw, forcing us to go with a battery that's chemistry produces a low internal resistance so the motor doesn't brown out the power supply.

PIC Selection

For our design we decided to go with the pic18f97j94 processor. One key problem about our setup is the use of two nintendo wii IR cameras. Because these cameras have a factory set I2C address that is not changeable, they cannot trivially be on the same I2C bus. Instead of trying to involve an external I2C multiplexer, we decided to use a processor that can handle 2 separate I2C buses simultaneously. This hurdle immediately narrowed down our selection and removed the pic18f452 from the list of possible processors.

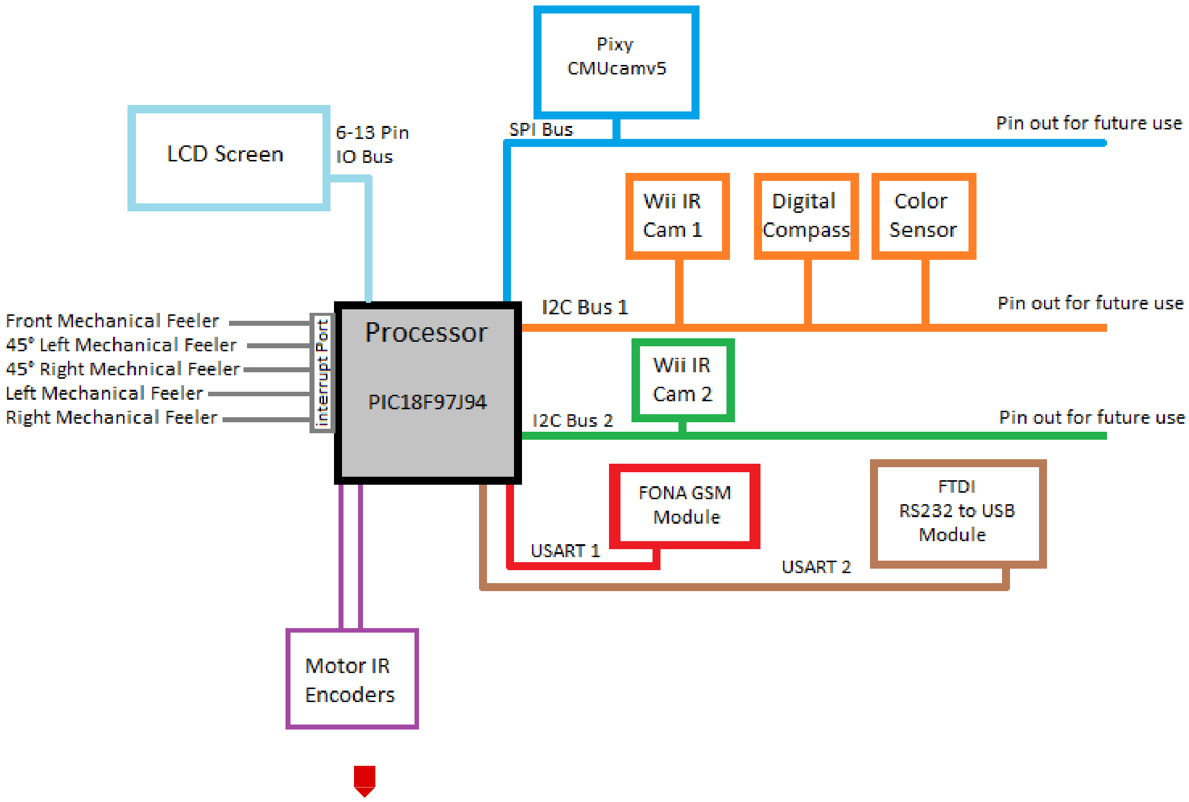
Aside from I2C, we also have communications taking place through SPI, UART, and possibly USB meaning we needed a processor that could handle these protocols as well. All processors that could handle two I2C buses could also handle all these necessary communications.

Based off of the large amount of sensors we are communicating with and our limit to a single core processor, the need for a processor that is fast enough to communicate with everything and interpret data in a timely manner was apparent. Looking through the pic18F family, we narrowed it down to the fastest processors that are offered which peaked at 64MHz.

We are anticipating a fairly complex program with the necessity to manage communications with various sensors, interpreting data from various sensors including 3 cameras, and general control algorithms. With the addition of a one-time FFT being used to initiate the robot the estimated program size is very large. To prepare for this we selected the processor that fit all previous criteria yet also had the most available program space. The largest size offered with the rest of our stipulations is 128kb, which is enough that we will not feel pressured to restrict our program size.

At this point we would be forced to select between the pic18f97j94 or the pic18f67j94. The only difference between these two processors is the cost and number of available I/O pins. For the 40c difference we decided to go with the pic18f97j94 for nearly double the I/O.

Communications Block Diagram



Risks

Our project contains a lot of risks that we need to be aware of in order for the progression of work to go smoothly and also to guarantee the success of the robot. One of our more severe risks is the possibility of errors during the PCB design and fabrication. This is a problem that although fixable, can be complex to troubleshoot and lead to many headaches and wasted time.

One of the more obvious and problematic risks is the possibility of a robot that does not act as expected or misinterprets the information its sensors are portraying. By misinterpreting the data being received by the sensors we risk events such as not finding the candle, running into a teammate, or signalling a false alarm. These are all events we will have to test vigorously for to make sure our robot acts and responds in predictable and controllable ways. A lot of these risks will be avoided by rigorous testing and tweaking of the algorithms used.

Depending on the area of final testing, we will have to make sure our robot has cell network connectivity. Because our robot heavily relies on the cell network for communication of the fire’s location, if we are in an area that prohibits cellular access then that will be a major risk to our success. This is not something we have direct control over and so in order to mitigate this problem we will need to make sure our GSM antenna is placed in a location that gives it the greatest reception and least interference.

One of the most worrying risks is the possibility of false starting or mishearing the tone of the alarm. To avoid this we are dedicating our entire processor’s power to an FFT to give us an accurate reading of the incoming frequency during the start of the competition. By creating an algorithm to interpret the data we will be able to create tune how we interpret this data to give us the most accurate tone response. Filtering out background noise will help greatly with avoiding false starts.

Budget

Our major cost is going to be our PCB. The cost of our PCB is going to be heavily reliant on the size of our board, and the shipping speed we need to receive our boards in an acceptable amount of time. Because we are doing mostly SMD components we have decided to also use a solder stencil which will add approximately 8$ onto our cost. These two parts alone are going to be our main source of cost. For a more detailed budget breakdown, please see the attached spreadsheet.

Qty	Description	URL	Cost per	Ext. Cost
	Drive Train			
1	Pololu Micro Metal Gearmotor Bracket Extended Pair	https://www.pololu.com/product/1089	$4.99	$4.99
2	Pololu Micro Metal Gearmotor 30:1 gearing, 1600mA draw	https://www.pololu.com/product/1093	$6.00	$12.00
1	Pololu Rubber/Plastic wheel with hub	https://www.pololu.com/product/1090	$6.98	$6.98
2	1/2" Metal Ball Coaster	https://www.pololu.com/product/953	$1.99	$3.98
1	Hall effect encoder pair	https://www.pololu.com/product/2598	$8.95	$8.95
	Power supply			
1	ZIPPY Flightmax 2100mAh 2S3P 7.4v	http://www.hobbyking.com/hobbyking/store/__8272_	$12.70	$12.70
1	IC REG LDO 3.3V 1A SOT223	http://www.digikey.com/product-detail/en/NCP1117S	$0.49	$0.49
1	IC REG LDO 5V 1A DPAK	http://www.digikey.com/product-detail/en/NCP1117D	$0.48	$0.48
	Sensors/IC's			
1	PIC18F97J94T - main processor	http://www.digikey.com/product-detail/en/PIC18F97J	$5.59	$5.59
1	LCD Screen	https://www.pololu.com/product/356	$8.95	$8.95
1	Broken/old Wii mote to salvage camera from	http://www.craigslist.com	$0.00	$0.00
1	Pixy camera (salvage from personal project)	http://charmedlabs.com/default/pixy-cmucam5/	$0.00	$0.00
1	HMC5883L compass sensor	http://www.digikey.com/product-detail/en/HMC5883L	$3.30	$3.30
1	FONA GSM Module	http://www.adafruit.com/products/1946	$0.00	$0.00
1	White LED for ground color detection	http://www.digikey.com/product-detail/en/158301240/	$0.41	$0.41
1	IC for ground color detection	http://www.digikey.com/product-detail/en/TCS34725F	$2.77	$2.77
	Passive Components			
	See seperate sheet labeled 'Passive Components'			
	Miscellaneous			
1	Board from DirtyPCB (also to act as body/frame of robot)	http://dirtypcbs.com/	$30.00	$30.00
1	Board from DirtyPCB (Pixy & Wii IR camera mounting)	http://dirtypcbs.com/	$14.00	$14.00
1	Stencil from Osh Stencil	https://www.oshstencils.com/	$8.00	$8.00
1	Micro Servo for Camera Apperatus Tilting	Tyler	$0.00	$0.00
1	Misc Shipping		$8.00	$8.00
1	Microphone	Broderick	$0.00	$0.00
5	misc connectors (Pixy, battery, LCD, etc.)		$0.80	$4.00
1	JST connector for the battery		$1.00	$1.00
				$136.59

References

Pixy:

http://www.cmucam.org/projects/cmucam5/boards/9
http://charmedlabs.com/default/pixy-cmucam5/
https://www.youtube.com/watch?v=J8sl3nMlYxM

Wii:

http://www.instructables.com/id/Wii-Remote-IR-Camera-Hack/
http://cdn.instructables.com/FQL/9ZSM/FY3KH9ED/FQL9ZSMFY3KH9ED.MEDIUM.gif