MicroMousr
ECE 445 Spring 2019
Design Document

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1. Introduction

1.1. Objective

As technology has evolved to become more capable and affordable, the world has seen a significant change in the way humans entertain themselves. While our entertainment has become more technologically advanced, the way we play with our pets has stayed relatively the same, despite there being plenty of room for improvement.

Petronics, a startup founded in 2014, looked to tackle this problem by creating an advanced robotic toy for cats. They accomplished this goal by creating Mousr, a cat toy that can operate autonomously or interactively through a user based app. This product contains cutting edge technology, but comes at a price point too high for the majority of consumers. After speaking with the team, we will be building a functional, scaled down product called MicroMousr, with comparable functionality at a lower price point.

1.2. Background

Petronics was founded with the goal of creating the best automated cat toy in the world. Their current product, Mousr, has had great success so far, but at its current commercial price of $149.99, it is only attractive to a relatively small market. This project is necessary to support the long term goal of the company by making this advanced technology available to a larger market.

1.3. High Level Requirements

1.3.1. PCB and sensor components must be able to fit in the physical body of the Mousr product.
1.3.2. Must have driving capabilities consistent with the Mousr product.
1.3.3. Electronic component cost must total less than 50% of current model.

2. Design

2.1. Block Diagram
Figure 1. Block Diagram
### 2.2. Physical Design

![Figure 2. Mousr Design (Source: Petronics.io)](image)

![Figure 3. Petronics App (Source: apple.com)](image)

3.4 x 2.2 x 1.4 inches ; 2.4 ounces

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### 2.3. Requirements and Verification

#### 2.3.1. Processing Subsystem

The processing subsystem is responsible for much of the system management within MicroMousr. A functional subsystem should be able to operate low energy Bluetooth communication, receive data transmission from sensor systems, and correctly drive a PWM signal to the Motor subsystem.

#### 2.3.1.1. Microprocessor

Component: Cortex M4 Processor
- 1.7 to 3.6 V supply voltage range
- 2Mbps supported in BLE mode
- 64 MHz internal oscillator
The Microprocessor will be a Cortex M4 with an embedded NRF Bluetooth chip set. This chip is capable of communicating with Petronic's pre existing Mousr app and will be able to drive a PWM for the motor control subsystem by handling sensor readings.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
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<tbody>
<tr>
<td>1. Process information to respond to Time of Flight sensor 400kHz serial bus</td>
<td>1. Use oscilloscope to verify that pwm signal matches frequencies and magnitudes required by motor/motor driver circuits.</td>
</tr>
<tr>
<td>2. Transmit PWM signal via GPIO connection to motor drivers</td>
<td>3. Connect to debugging tools via JTAG connection</td>
</tr>
<tr>
<td>3. ARM processor capabilities as required by Petronics</td>
<td>4. Install UART application from Nordic Semiconductors to test sending and receiving messages to device over 2.4 GHz BLE connection.</td>
</tr>
<tr>
<td>4. Transmit and receive BLE signals</td>
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2.3.2. Controls Subsystem

The controls subsystem consists of an array of sensors that communicate environmental changes to the processing subsystem. In order to function effectively, the subsystem must be able to transmit real time changes with minimal latency using firmware that allows for powering on or off with minimal recalibration.

2.3.2.1. Time of Flight Sensor

The time of flight (ToF) sensor should be able to accurately sense cat activity and obstacles at a 2 meter range with no blind spots. The sensor should rest in a location at the top portion of the body for full visibility of surroundings.
Operating the device in shadows, darkness, or intense sunlight should not be a concern. The sensor emits a laser invisible to the human eye coupled with built-in infrared filters. These considerations make the sensor data independent of obstacle reflectivity.

Component: Optical 200cm Distance Measuring Chip
- Operating Voltage 2.6 to 3.5 V
- 4.40 x 2.40 x 1.00 mm

<table>
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<tr>
<td>1. <em>Must be capable of detecting objects such as cats, humans, and other obstacles at a range up to 2 square meters from the device with no blind spots.</em></td>
<td>1. A. Connect the VL53L0CXV0DH/1 to the nRF52832-QFAA.</td>
</tr>
<tr>
<td>2. <em>The chip must fit on the board without losing distance capabilities and without requiring excessive PCB layout adjustment.</em></td>
<td>B. Through the ARM programming interface of the nRF52832-QFAA, begin the set-up function calls of the laid out in the VL53L0CXV0DH/1 manual.</td>
</tr>
<tr>
<td></td>
<td>C. During offset calibration, set up a white surface in a dark environment, 100mm away from the VL53L0CXV0DH/1, and finish calibration.</td>
</tr>
<tr>
<td></td>
<td>2. During PCB design, the chip must not be printed directly on to the board since it will have to be at a different angle than the board. Instead the board should be printed with spots for the chip to be soldered at the correct angle, and this should be at the location on the board that will be the front of the mouse.</td>
</tr>
</tbody>
</table>
2.3.2.2. Inertial Measurement Unit (IMU)

The inertial measurement unit (IMU) will be composed of a gyroscope and accelerometer. The gyroscope measures device rotation rate and the accelerometer measures the rotational position around those axes, giving the device 6 degrees of freedom.

Requirements:
1. The IMU must be able to communicate with the M4 processor via I2C or SPI interface.
2. The IMU must accurately detect when the MicroMousr is lifted, tilted, or rotated, and transmit sensor readout with minimal latency (100-150 Hz sample rate).

2.3.2.3. Control Algorithms

To achieve expected vehicle operation, the algorithms driving the motor subsystem must balance sensor input with appropriate motor performance.

Requirements:
1. Algorithms should allow the moving vehicle to self-adjust based on sensor data.

2.3.3. Communication Subsystem

Full functionality of our device requires proper communication with the Mousr smartphone application

2.3.3.1. Petronics App

The device will connect to the existing Petronics app via low energy Bluetooth (BLE) connection. BLE allows the device to operate with minimal power consumption as the device is kept constantly in sleep mode until a connection is initiated.

Requirements:
1. Communicate signals at 2.4 GHz BLE frequency while transferring data at rates up to 1 Mb/s.
2. Use Bluetooth to communicate user input signals to operate controls subsystem.

2.3.4. Power Subsystem

2.3.5. Motor Subsystem

2.3.6. Interface Subsystem

2.3.6.1. Charging/Debugging Connection

Component: Custom micro USB-JTAG connection

<table>
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<tr>
<td>1. Must be capable of connecting with and charging the Li-Ion battery.</td>
<td>1. A. Discharge a 4.2V li-ion battery.</td>
</tr>
<tr>
<td>2. Cable must be able to debug through micro USB-JTAG redesign.</td>
<td>B. Connect battery to Output of BQ24090DGQR, which is connected to a voltage supply of at least 6.5V, but no more than 12V.</td>
</tr>
<tr>
<td>a. Reserve one pin for processor clock, two pins for bluetooth chip</td>
<td>C. Once output of pin 8 on the BQ24090DGQR goes high, use voltmeter to make sure the battery outputs a voltage of</td>
</tr>
</tbody>
</table>
4.2V +/- 1%
2. Upon connecting to device through USB, must be capable of connecting to ARM Development Studio with scripting interface

Figure 4. VL53L0X Distance Measuring Accuracy

2.4. Circuit Schematics

![Circuit Diagram]

Figure 5. CoretexM4 to VL53L0X connection

2.5. Calculations

In order to have proper motor control, we will need to have a functioning H-Bridge Motor Driver circuit. The basic design of the circuit can be seen below.
Figure 6. Basic H-Bridge Driver Circuit

The switches in this example are really parallel combinations of diode and transistor, as seen below.

Figure 7. Extrapolated Switch Design

Because DC motors are essentially a series combination of inductor and resistor, we can view the DC motor in the center of Figure 6 as an inductive load. Therefore, the voltage drop across the motor can be defined by the following:

\[ V = L \frac{di}{dt} + RI. \]

Assuming zero voltage across the motor (ideal case with no transistor or diode voltage drops), we can make the equation
\[ 0 = L \frac{di}{dt} + RI \]

which equivalently can be considered

\[ \frac{di}{dt} = -\frac{RI}{L} \]

Assuming \( I = I_0 \), we can find the solution as the following

\[ I(t) = I_0 e^{-\frac{t}{\tau}} \]

Where \( \tau = \frac{L}{R} \). From there we can calculate the percentage speed change with varying time by multiplying the operating frequency of our PWM signal with the percentage we are driving the PWM at.

3. Discussion of Ethics and Safety

We must pursue this project in good faith of ourselves, the engineering department, the external company, and their customers. As stated in the IEEE Code of Ethics Item 1, we must “hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment.” In light of this, there are several potential safety hazards involved with designing and prototyping the MicroMousr system.

We will prototype our device only in approved spaces with adequate equipment and supervision. We must exercise caution while soldering and working with components of the battery, as emphasized in the Safety Quiz and safety guidelines of this course. ECE 445 safety guidelines state that designs utilizing a lithium ion battery must work with extra caution. The Safe Battery Practices documents states that the battery must always be stored in a secure location with the terminals covered by insulating material (Section III). Additionally, we “will be REQUIRED to find the Material Safety Data Sheet (MSDS) and data sheet” and we must keep this documentation on hand at all times in the laboratory (Section IV). We must ensure we NEVER over charge, over discharge, over heat, or short circuit the battery.

We must also ensure that the final product is safe, with no risk of the human or the cat exposing internal electronics or otherwise misusing the product in a way that could produce electrical harm. To do this, we need to consider all possible environments the product may be used in. The parts we choose should be able to withstand environments such as extreme temperature or humidity. The sensors we are considering are functional at temperature ranges at least -20°C ~ 70°C. Should the cat drop the device into a sink or toilet, the sensors may malfunction nobody should be harmed at a maximum charge of only 6 volts. There should be no risk of dropping the device in a way that could open the mechanical chasse and expose internal components. The strong polycarbonate...
casting should protect the device from external damage, and the electronics should be properly mounted to prevent internal damage. Leaving the device in front of a window should not cause issues for the product.

In addition to prioritizing physical design safety concerns, there are ethical considerations to be made when working closely alongside an established company. The ACM Code of Ethics Item 1.2 states “Examples of harm include unjustified physical or mental injury, unjustified destruction or disclosure of information, and unjustified damage to property, reputation, and the environment. This list is not exhaustive.” To adhere to these guidelines, we must keep proprietary information out of reach of unauthorized parties and respect the donation of time and supplies provided by Petronics and the engineering department. We must respect the reputation of Petronics and be frugal with the resources they provide for us. Misuse of available resources may lead us to directly break IEEE Code of Ethics Item 9, “to avoid injuring others, their property, reputation, or employment by false or malicious action.”

We must adhere to ACM Code of Ethics Item 1.7, “honor confidentiality.” To protect the integrity of Petronics, the device should in no way allow customers or unauthorized authorities to gain access to any design information. This includes firmware and specific component pricing.

Throughout the development phase, our project team must work together “to assist colleagues and co-workers in their professional development and to support them in following this code of ethics” (IEEE Code of Ethics Item 10). We will each support one another in our own development and strive to make the design process as seamless as possible. We do this as we strive “to achieve high quality in both the processes and products of professional work” (ACM Code of Ethics Item 2.1).

4. Citations


Adafruit Learning System. “Software: nRF UART App.” [Link]

Petronics.io. Mousr. [Product, 2018.] [Link]
