EE16B Final Project Write-up

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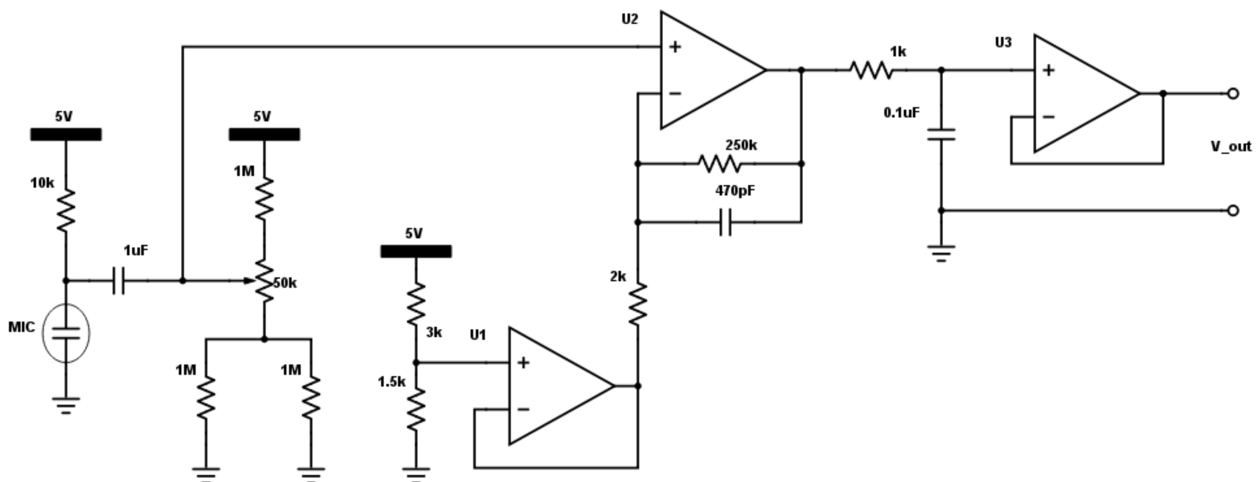
<u>Circuit Design</u>



The circuit for our microphone consisted of an active second-order low pass filter, to filter out higher frequency noise. The first stage of our circuit was a non-inverting amplifier first-order low pass filter, where the virtual ground was buffered to avoid loading the input circuit. The active filter provided a gain of

$$G = \frac{R_b}{R_a} = \frac{(250\ k\Omega)}{(2\ k\Omega)} = 125$$

in order to amplify the signal we would feed into the MSP to a useable level. The active filter had a cutoff frequency of

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(250\ k\Omega)(0.47\ nF)} \approx 1400\ Hz$$

The second stage of our circuit was a simple first-order RC low pass filter. The passive filter had a cutoff frequency of

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(1\ k\Omega)(01\mu F)} \approx 1600\ Hz$$

This cascades the two first order filters into a second order filter, to achieve better attenuation of unwanted high frequency noise. The unity buffer at the end avoided loading the circuit we attached the output of the filter to. Finally, our circuit was not designed with respect to ground but with respect to a reference voltage of about 1.66 V. This was to counteract the DC bias of 1.66 V that was present, essentially “subtracting out” the bias. If we amplified the microphone signal along with the DC bias, our calculations became distorted and jumbled. Thus, we have a voltage divider at the bottom to establish the reference voltage as our new "ground".

PCA Classification

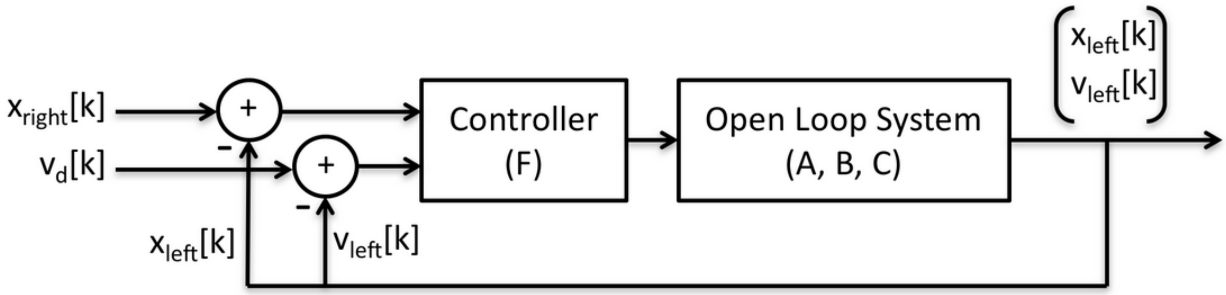
By far, the hardest part of the project for the PCA team was determining which words were unique enough. One of the toughest things to reconcile about finding unique words was that in some basis constructed from four words, two words could look extremely different but in another basis, the same words could occupy the same portion of the subspace, making k-means impossible. Our initial impression of a "unique" word was a word that had different number of syllables. This appeared to work temporarily, however, once we transitioned to using our own microphone circuit, the flaws in this methodology quickly became apparent. Then, we realized that the number of syllables wasn't really the important factor, rather, the location of stresses on syllables was the important factor. With that knowledge in mind, selecting words became an easier task. This is why I believe our final words were very unique and fairly easily identifiable.

Our four words were: "bop," "Sahai," "eecs eecs," and "slow." In addition, to being rather identifiably unique words, there was a certain way in each word was enunciated. "Bop" was deliberate and extremely quick -- almost like a snap. "Sahai" was said more naturally, with an emphasis placed on the second syllable for ease of classification. "Eecs eecs" was short and deliberate with the key consideration being an equal stress placed on both syllables. Lastly, "slow" was more drawn out, with the emphasis on extending the vowel sound of the word. It had a natural rise and fall as seen in the audio signal.

Another challenging part of the PCA classification was consistently recording the words. Even the slightest delay could cause an issue. Furthermore, a common thing that would happen was that we would miss the first recording, so a random noise sample would be included along with all the regular data. This was realized and accounted for by just being more prepared for the recording to start, and once we took this strategy, our recordings generated more consistent data.

<u>Control Theory</u>

The closed loop controller for the left wheel was designed according to the diagram below. The right wheel controller was designed to have controls symmetric to the left wheel.



The control equations were derived as follows:

$$\vec{x}[k+1] = A\vec{x}[k] + Bu[k]$$

$$\vec{y}[k] = C\vec{x}[k]$$

$$B = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}, \qquad C = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$A = \begin{bmatrix} 1 & T_s \\ 0 & 1 \end{bmatrix}, \qquad T_s = 200ms$$

Putting the equations together:

The left wheel:

$$\begin{bmatrix} x_{left}[k+1] \\ v_{left}[k+1] \end{bmatrix} = \begin{bmatrix} 1 & T_s \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_{left}[k] \\ v_{left}[k] \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} u[k]$$

The right wheel:

$$\begin{bmatrix} x_{right}[k+1] \\ v_{right}[k+1] \end{bmatrix} = \begin{bmatrix} 1 & T_s \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_{right}[k] \\ v_{right}[k] \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} u[k]$$

For both wheels, data was collected and b_1, b_2 for each wheel were found as follows:

$\vec{u}[k]b_1 = \vec{x}[k+1] - \vec{x}[k] - T_s\vec{v}[k]$

$\vec{u}[k]b_2 = \vec{v}[k+1] - \vec{v}[k]$

Let:

$P = \vec{u}[k]$

$\overrightarrow{b_x} = \vec{x}[k+1] - \vec{x}[k] - T_s\vec{v}[k]$

$\overrightarrow{b_v} = \vec{v}[k+1] - \vec{v}[k]$

The least squares solution for $Pb_1 = \vec{b}_x$ was found to be $b_1 = (P^TP)^{-1}P^T\vec{b}_x$ and for $Pb_2 = \vec{b}_v$ it was found to be $b_2 = (P^TP)^{-1}P^T\vec{b}_v$.

The closed loop equations were derived as follows:

The left wheel used right wheel information:

$$\overrightarrow{y_{ref}}[k] = \begin{bmatrix} x_{right}[k] \\ v_d[k] \end{bmatrix} = \begin{bmatrix} right\ wheel\ distance \\ desired\ veloctiy \end{bmatrix}$$

The right wheel used left wheel information:

$$\overrightarrow{y_{ref}}[k] = \begin{bmatrix} x_{left}[k] \\ v_d[k] \end{bmatrix}$$

Using that information, the closed loop equation for the left wheel are shown below. The equations for the right wheel are symmetric to the equations for the left wheel.

$$\vec{y}[k] = \begin{bmatrix} x_{left}[k] \\ v_{left}[k] \end{bmatrix}, \qquad \overrightarrow{y_{ref}}[k] = \begin{bmatrix} x_{right}[k] \\ v_d[k] \end{bmatrix}$$

$$\vec{e}[k] = \overrightarrow{y_{ref}}[k] - \vec{y}[k]$$

$$u[k] = F\vec{e}[k], \qquad F = [f_1 \quad f_2]$$

$$\vec{x}[k+1] = A\vec{x}[k] + BF\vec{e}[k]$$

$$\vec{x}[k+1] = A\vec{x}[k] + BF\left(\overrightarrow{y_{ref}}[k] - C\vec{x}[k]\right)$$

$$\vec{x}[k+1] = (A - BFC)\vec{x}[k] + BF\overrightarrow{y_{ref}}[k]$$

$$A_{closed-loop} = A - BFC, \qquad B_{closed-loop} = BF$$

Eigenvalues were placed based on the equations below:

$$Det\left(A_{closed-loop} - \lambda I\right) = \lambda^2 + (b_1 f_1 + b_2 f_2 - 2)\lambda + 1 - b_1 f_1 - b_2 f_2 + b_2 f_1 T_s$$

The eigenvalues were chosen to be: $\lambda = \pm\lambda_0$

Comparing coefficients with: $\lambda^2 + 0\lambda - {\lambda_0}^2$

The following equations were obtained:

$$(b_1 f_1 + b_2 f_2 - 2) = 0$$

$$1 - b_1 f_1 - b_2 f_2 + b_2 f_1 T_s = -{\lambda_0}^2$$

Which allow to solve for $f_1\ and\ f_2$.

To control the wheels, the information in $F\vec{e}[k]$ was added to the code provided for the MSP430. While the graphs showed excellent feedback and controls that work, it was difficult to test on the car. λ_0 was initially chosen to be 0.5, but the car would create a circle in one direction, then after some waiting period it would undo that by circling in the other direction. Because of this slow feedback, smaller eigenvalues of 0.2 were tried, though this gave similar results. The circling issue was not as significant when eigenvalues were placed to be above 0.9, however feedback appeared to be happening slowly so the car made wide circles.

After much trial and error and multiple collections of data to identify what was causing the controls to behave unexpectedly, it was realized that the issue was the result of a false signal coming from noise in the circuit. To come to this conclusion, the following steps were taken:

1. Output how the control responds by displaying the position and velocity to the serial monitor and turn the wheels manually. Observing the values displayed showed that the controls were working as expected with the position and velocity adjusting as modeled by the control equations.
2. Connect the battery and observe the values in the serial monitor. Now the wheels were automatically turning, however only the left wheel would turn while the other was stopped. This is where the issue was detected. Even though only one wheel was turning, the position of both of the wheels was incrementing at a similar rate. It stopped incrementing when the left wheel was stopped manually. Thus it was concluded that the encoder was detecting noisy feedback and gave false readings.
3. Probe the faulty encoder and see if there is noise on the oscilloscope. This revealed noise on the right encoder when the left wheel was spinning. Capacitor filters were successfully applied and this slowed the false incrementing of the right encoder though it did not completely prevent the encoder from giving false readings.

After step 3, the car responded to controls significantly better although the issue where the right wheel's position was falsely incrementing was not completely resolved. As a result, the left wheel was spinning more than expected which caused the car to make a wide right turn in a circle. Even though the signal noise issue was not completely resolved, it was clear that the controls were working as expected and that the car had the potential to go in a straight path in the absence of noise from the circuit.

Controls for turns were implemented in the code uploaded on the MSP430. Turning was implemented by incrementing the position of one wheel to create a difference in wheel positions. This allowed the car's feedback control system to take over and turn the car. However, due to our encoder feedback issues, this did not work as it should have. Instead, we had to override the controls by directly powering the wheels in open-loop.

General

This was a difficult and rewarding project. Our group spent many hours working on this project outside of lab time. Although we were unable to successfully meet all of the project specifications in time, we found the project to be a great learning experience. One of the most notable things learned was that the real world is much more difficult to work with due to the many sources of noise and variables beyond our control and understanding. One suggestion to improve this project for next semester would be to allow students to begin working on it earlier in the semester. This could be done by eliminating the Front End labs which consumed 3 weeks and were less significant compared to this project.

<u>Photos</u>