EMG and ECG Data Logger for Gamified Rehabilitation

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Background/Purpose

Proprioception: Awareness of the position and movement of the body

Physical Therapy

Neurodegenerative Diseases

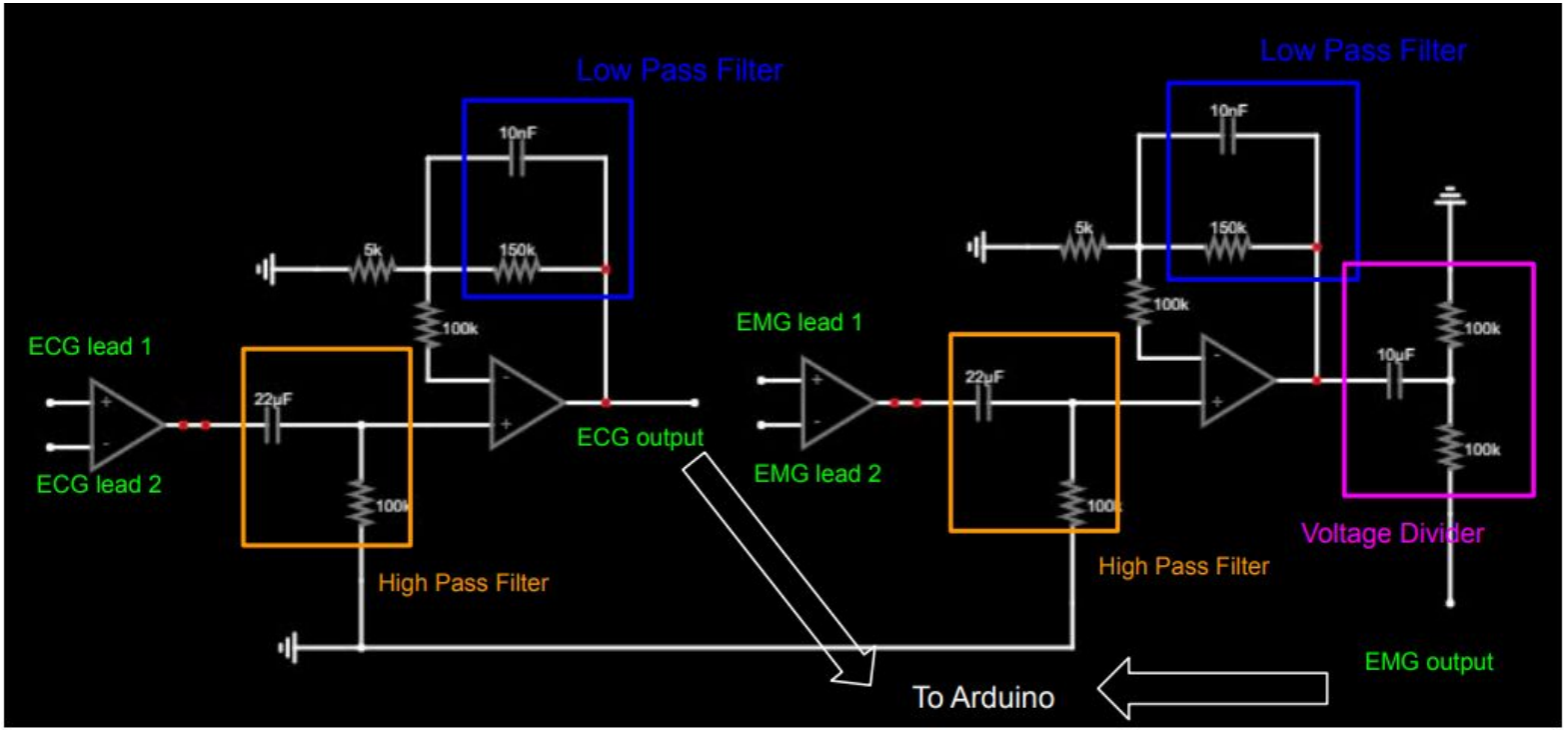
GOAL:

Creating a versatile EMG and ECG analog system for Arduino based data logging and video game muscle rehabilitation

Design & Constraints

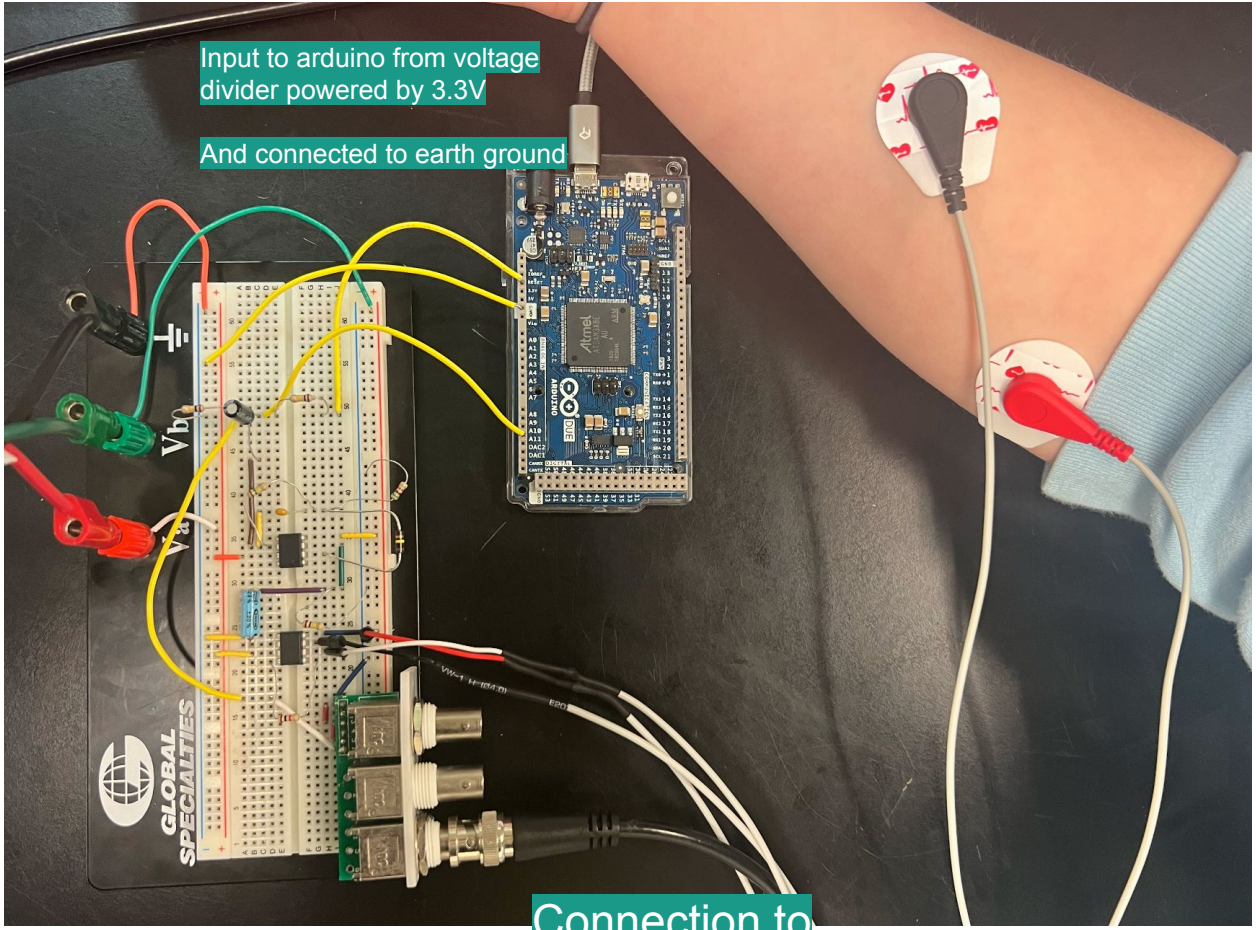
- To aid rehab for muscle injuries or muscle movement-related brain injuries
- 2 circuits containing
  - Differential amplifier
  - Operational amplifier with a low pass and a high pass filter
  - Voltage divider
- Inputs contain ECG and EMG signals
- Output converts analog signals to digital to be processed
- EMG to control the video game and ECG to show heart bpm while playing
- Video game chosen
  - Jetpack Joyride

Analog Design Overview



With the voltage divider, we are able include the negative voltages by scaling everything up.
Gain1 =1 + 50.5k/RG = 1 +50.5k/1k = 51.5 (gain of the first op-amp)
Gain2 = 1 + R2/R1 = 1 + R||C/100k = 1 + (100k/(1 + 0.0015jw)) (gain of the second amplifier)

Power supply to +/- 9V and earth ground



Two input electrodes on forearm and third reference electrode on abdomen

Connection to oscilloscope

Data Logger

Arduino firmware

- Arduino sends time and voltage
  - 115200 baud rate
  - Sampling rate of 200Hz.
- Sample structure is string “[t v]”
  - Converted to 2 Matlab vectors
- Using altered code, sampling rate of 1 kHz was achieved

```
//Initialize variables
  int i = 0;
  unsigned t = 0;   // the time variable
  unsigned v = 0;   // the voltage value
  unsigned s=0;  // start time
  const int analogInPin = A11;

//Set baud rate and input pin
  void setup() {
  Serial.begin(115200);
  pinMode(analogInPin, INPUT);
  s=millis();
 }

//Loop for reading samples of data
void loop() {
  t=millis()-s;    //the elapsed time in milliseconds
  v=analogRead(analogInPin);

  Serial.print(t); // time
  Serial.print(' ');
  Serial.println(v);  // voltage

  delay(5);      // sampling interval in ms
}
```

https://github.com/joannamialkowska

Unprocessed EMG data logged using MATLAB

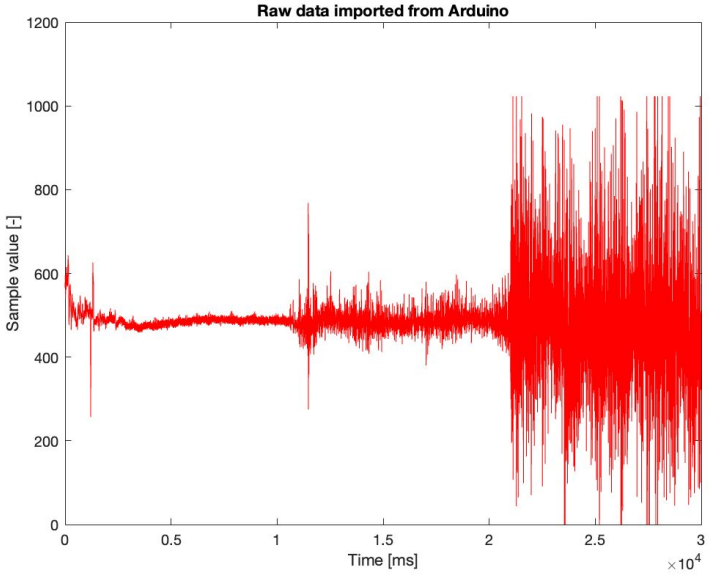


Fig. Plot showing raw data for 10s period of no contraction, 10s period of low contraction and then 10s period of high contraction

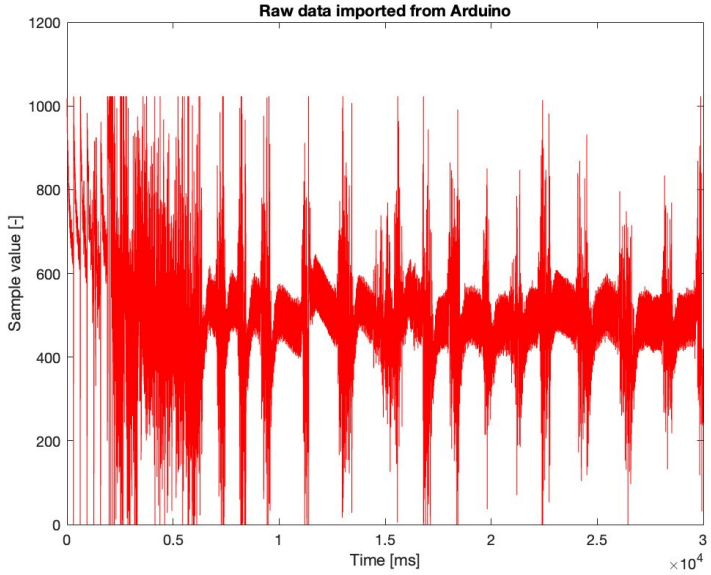


Fig. Plot showing raw data for rhythmic pulses of contraction

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MATLAB EMG data processing - correct units and highpass filter

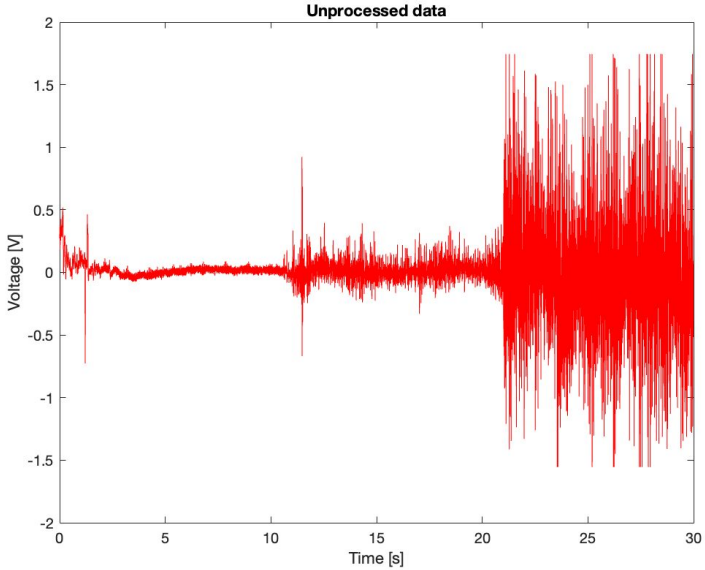


Fig. Plot showing unprocessed data after correcting units - removing average and converting ms to s.

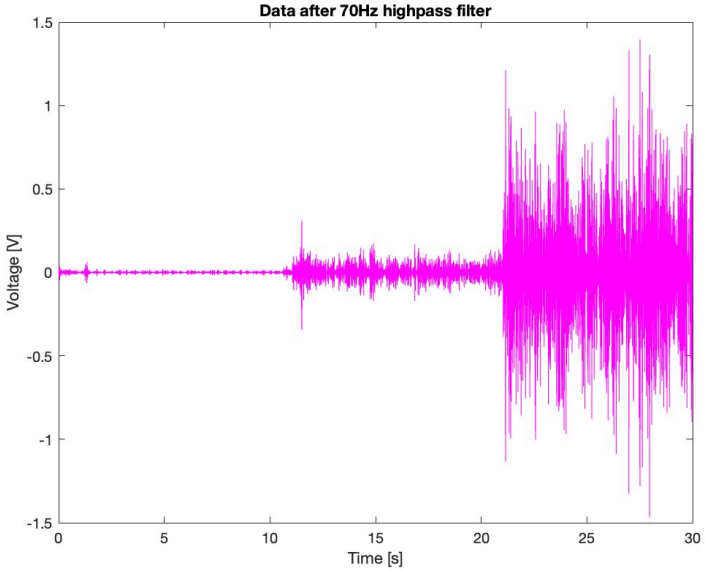


Fig. Plot showing signal after applying 70 Hz high pass butterworth filter. Cutoff frequency is above 60Hz to remove mains hum.

https://github.com/joannamialkowska

MATLAB EMG data processing - power plot

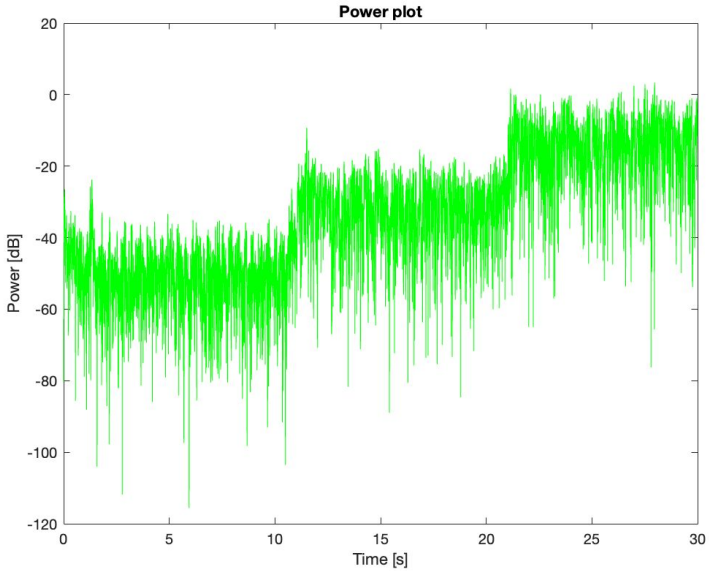


Fig. Power plot showing signal power for no, low and high contraction.

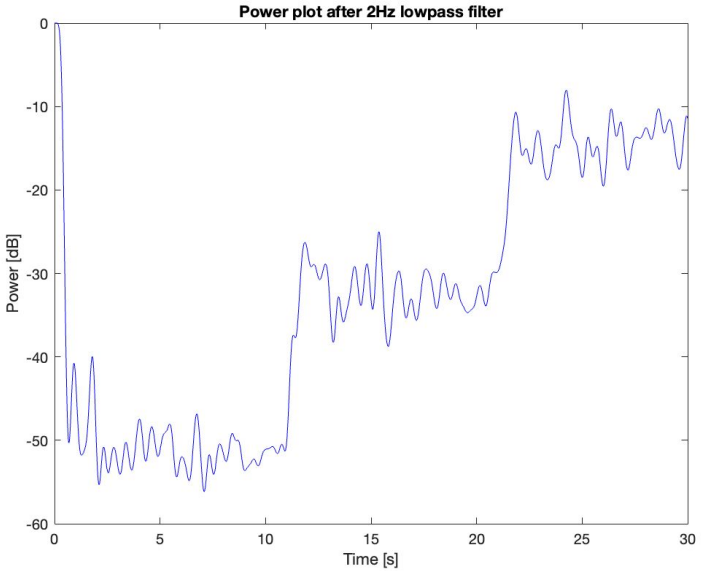


Fig. Power plot after applying 2 Hz low pass butterworth filter showing signal power for no, low and high contraction.

https://github.com/joannamialkowska

Gamified Rehab Application

EMG Video Game Arduino Code

- Take the EMG input to process through Arduino and tell keyboard to press spacebar to play the game after voltage threshold is passed
- Validated for two people, but next step would automating setting threshold for key press
- Video Demonstration (30 second video)

```
#include "Keyboard.h"
int i = 0;
unsigned t = 0;   // the time variable
unsigned v = 0;   // the voltage value
unsigned s=0;  // start time

const int analogInPin = A11;
const int emgPin = A11;
const int threshold = 518;
int emgValue = 0;
int prevEmgValue = 0;
bool muscleContraction = false;

void setup() {
  Serial.begin(9600);
  // Serial.println('Test');
  pinMode(analogInPin, INPUT);
  Keyboard.begin();
  Keyboard.end();
 }

void loop() {
  emgValue = analogRead(emgPin);

  // Check if muscle contraction is detected
  if (emgValue > threshold) {
    muscleContraction = true;
     Serial.println(emgValue);
    Serial.println('a');
    Keyboard.write(' ');
  } else {
    muscleContraction = false;

  }

  // Update previous EMG sensor reading
  prevEmgValue = muscleContraction;

  // Add a delay to avoid continuous readings
  delay(10);
}
```

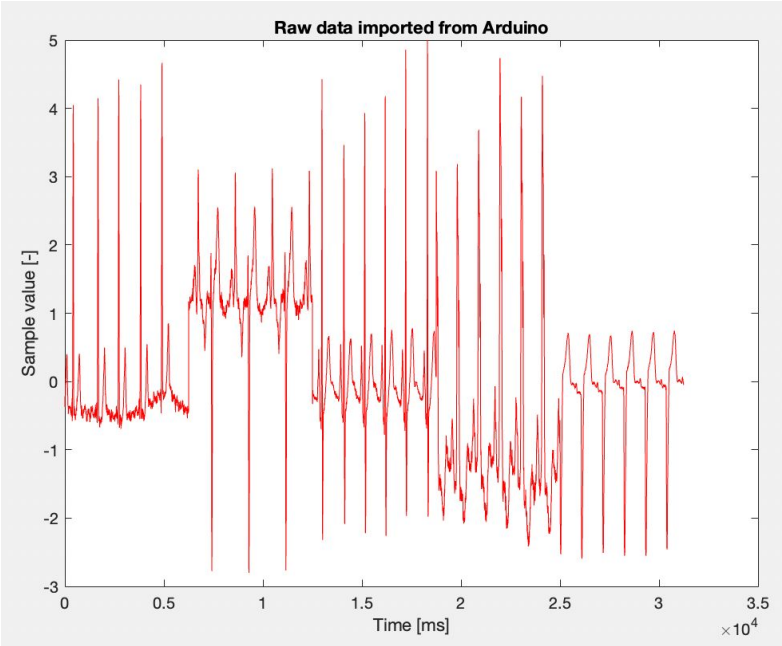
https://github.com/breestrammy

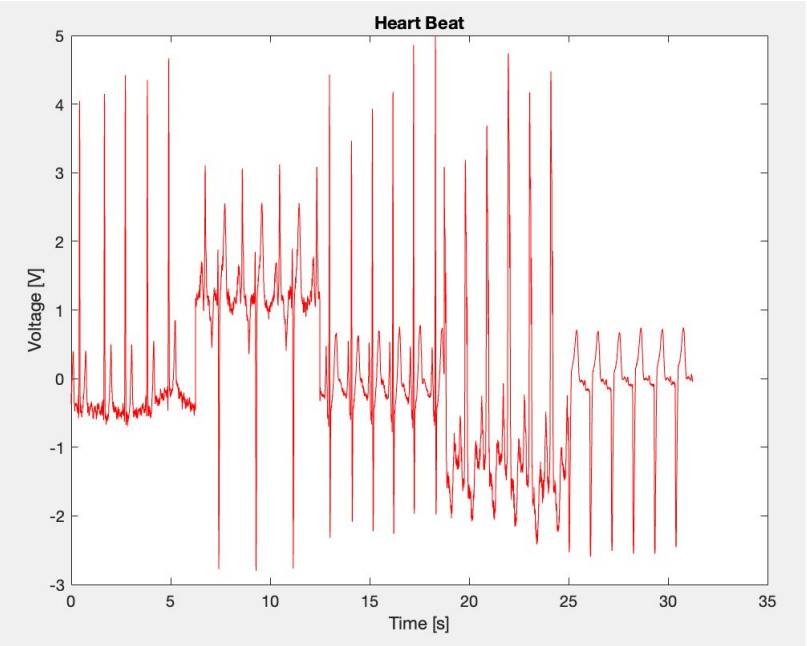
Heartbeat Monitor

ECG MATLAB Code

```
%% ECG Data Processing

%% Raw Data
load('ECG30.mat');
t = [0:5:31245]';                          % time vector in ms
v = ECG30(:,1);                            % voltage vector from arduino

figure(9);                                 % Raw data plot
plot(t,v,'r');
title('Raw data imported from Arduino');
xlabel('Time [ms]');
ylabel('Sample value [-]');

%% Correct time to seconds
t = t./1000;                               % ms --> s

%% Heart Beat plot
figure(1)                                  % Heart beat plot
plot(t,v,'r');
title('Heart Beat');
xlabel('Time [s]');
ylabel('Voltage [V]');

%% Find Heart Rate
[TF,P] = islocalmax(v);                    % TF = vector saying value is a local max

figure(8)                                  % test plot
plot(t,v,'-r',t,P,'-b');
title('Test for Prominence');
xlabel('Time [s]');
ylabel('Voltage [V] or Prominence');
```

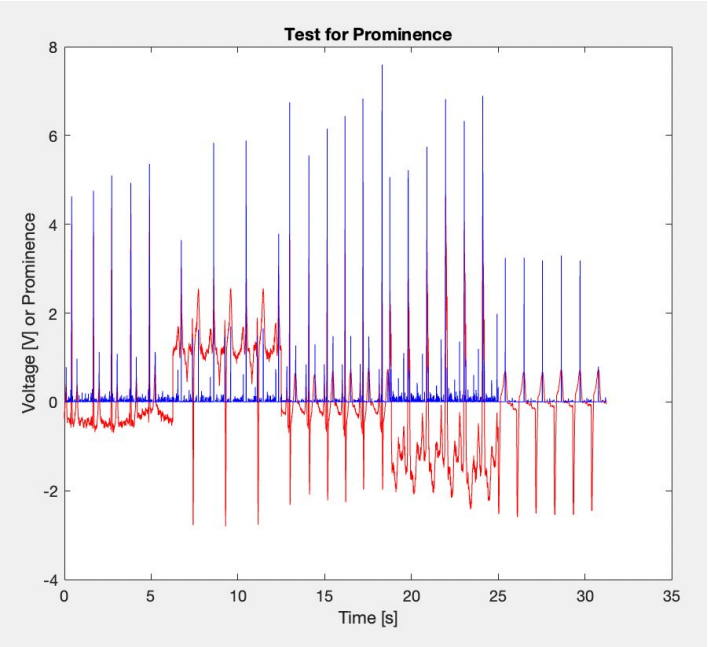
MATLAB ECG - Heart Beat Plot





ECG MATLAB Testing Prominence

```
[TF,P] = islocalmax(v);

figure(8)
plot(t,v,'-r',t,P,'-b');
title('Test for Prominence');
xlabel('Time [s]');
ylabel('Voltage [V] or Prominence');

for i = 1
    if P(i) <= 3.3
        P = P([1:i-1 i+1:end]);
        TF = TF([1:i-1 i+1:end]);
        t = t([1:i-1 i+1:end]);
        i = i + 1;
    else
        i = i + 1;
    end
end
```



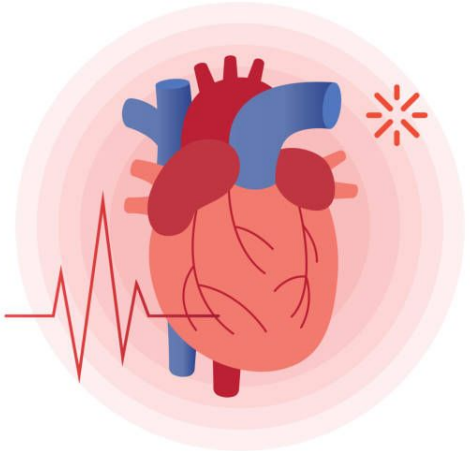
ECG MATLAB Code

```
%% Find Heart Rate
[TF,P] = islocalmax(v);                 % TF = vector saying value is a local max

figure(8)                               % test plot
plot(t,v,'-r',t,P,'-b');
title('Test for Prominence');
xlabel('Time [s]');
ylabel('Voltage [V] or Prominence');

for i = 1
    if P(i) <= 3.3                      % if the prominence (P) is less than 1:
        P = P([1:i-1 i+1:end]);         % get rid of the value for P, TF,
        TF = TF([1:i-1 i+1:end]);       % and time so it will only
        t = t([1:i-1 i+1:end]);
        i = i + 1;                      % consider large local maxs
    else
        i = i + 1;                      % move on to next index
    end
end

heart_rate = zeros([1,length(t)-1]);    % allocating space for heart rate

for m = 1:length(t)-1
    heart_rate(m) = 60./(t(m+1)-t(m));  % finding rate between each local max time
    m = m + 1;                          % move on to next index
end

%% Intensity of Heart Beat
amplitude = max(v) - min(v);            % Calculate amplitude of heart rate signal

%% Display results
disp(['Heart Rate: ', num2str(heart_rate), ' bpm']);
disp(['Intensity of Heart Rate Signal: ', num2str(amplitude),' ']);
```

Applications

Neurodegenerative Diseases Global Stats

- Parkinson's | affecting 9.4 million in 2020
- Huntington's | affecting 400 thousand in 2022
- ALS | affecting 200 thousand in 2018
- Etc.



Loss of Motor Control | Loss of Muscle | Tremors | Rigidity

Cardiovascular Health | Physical Therapy | Quality of Life

Further Research

1. Current state of firmware and software limits EMG and ECG simultaneous data collection
2. Apply data logger to a game-control system
3. Firmware could be optimized to explore
    a. Automated threshold setting for key press
    b. Higher sampling frequencies
    c. Better preprocessing

References

[1] Bonanni R, Cariati I, Tarantino U, D'Arcangelo G, Tancredi V. Physical Exercise and Health: A Focus on Its Protective Role in Neurodegenerative Diseases. J Funct Morphol Kinesiol. 2022 Apr 29;7(2):38. doi: 10.3390/jfmk7020038. PMID: 35645300; PMCID: PMC9149968.

[2] Firoz CK, Jabir NR, Khan MS, Mahmoud M, Shakil S, Damanhouri GA, Zaidi SK, Tabrez S, Kamal MA. An overview on the correlation of neurological disorders with cardiovascular disease. Saudi J Biol Sci. 2015 Jan;22(1):19-23. doi: 10.1016/j.sjbs.2014.09.003. Epub 2014 Sep 6. PMID: 25561878; PMCID: PMC4281592.

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[4] Sujkowski A, Hong L, Wessells RJ, Todi SV. The protective role of exercise against age-related neurodegeneration. Ageing Res Rev. 2022 Feb;74:101543. doi: 10.1016/j.arr.2021.101543. Epub 2021 Dec 17. PMID: 34923167; PMCID: PMC8761166.

[5] Wheeler B, Taylor-Amos A. BENG 152 Lab 05 Instrumentation Amplifiers. Canvas. 2024

[6] Wheeler B, Taylor-Amos A. BENG 152 Lab 08 Arduino. Canvas. 2024

Acknowledgements

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