Design and Implementation of a Rudimentary Electrocardiogram using Operational Amplifier LM741

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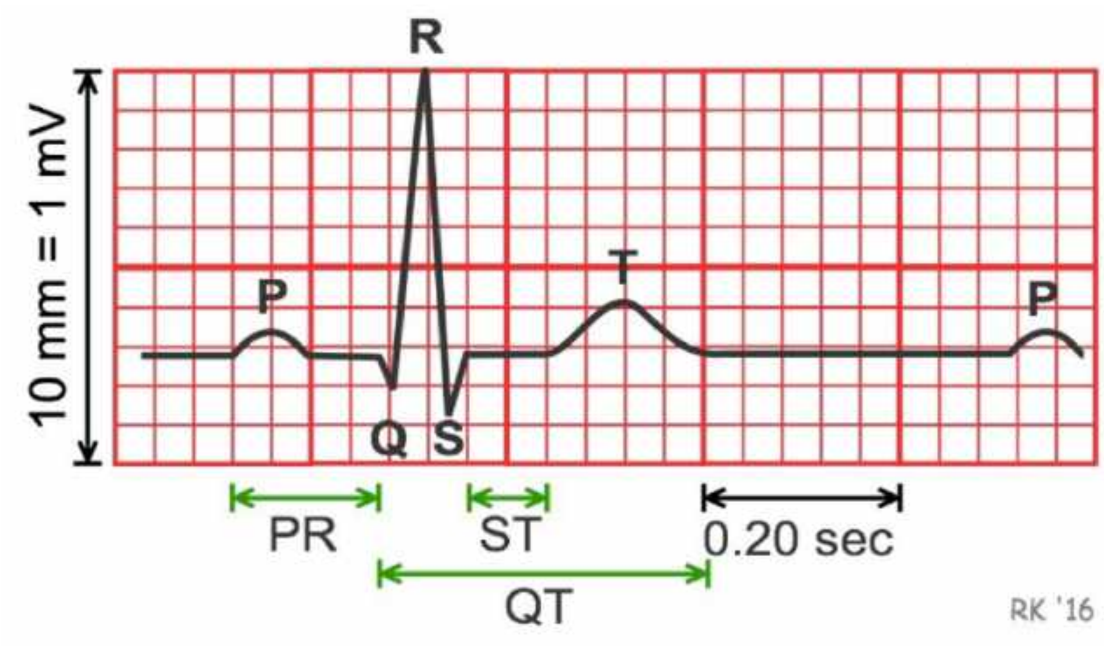
INTRODUCTION

Objective: To design a rudimentary electrocardiogram (ECG) using Op-Amp 741.
An Electrocardiogram (ECG) is a medical test used to measure the electrical activity of the heart over a period of time. It is a non-invasive and commonly performed procedure that helps healthcare professionals assess the heart's health.

How It Works:

- Electrodes are placed on the chest to detect electrical signals produced by the heart.
- These signals are recorded as waves on a graph, showing the timing and strength of heart activity.



Explanation of the Electrocardiograph:
The heart cycle consists of three stages, the first stage being Diastole, Systole and Involumetric Relaxation of the heart.
Diastole is the longest stage spanning over 0.5 seconds, it is shown by the end of the S point of the graph till the end of the T phase. In this phase the heart fills up with blood and the

cardiac muscles are relaxed, hence the lower peak.

The next stage is known as Systole, this stage lasts for 0.3 seconds. It is shown by QRS peak shown in the graph. Since the cardiac muscles contract, and the blood flows out, the electrical signal is higher.

Lastly the Involumetric Relaxation of the heart lasts for about 0.2 seconds, and the heart muscles are in relaxed state, thus constituting the nearly flat line from the end of the T phase till the next Diastole.

PROPOSED WORK

a. Design Approach/System Model :

This Electrocardiogram is based on the cardiac pads detecting the electrical signals from the cardiac cycle, and then the amplification of the said signals by the operational amplifier and the resistor network, thus enabling digital visualization of the signal.

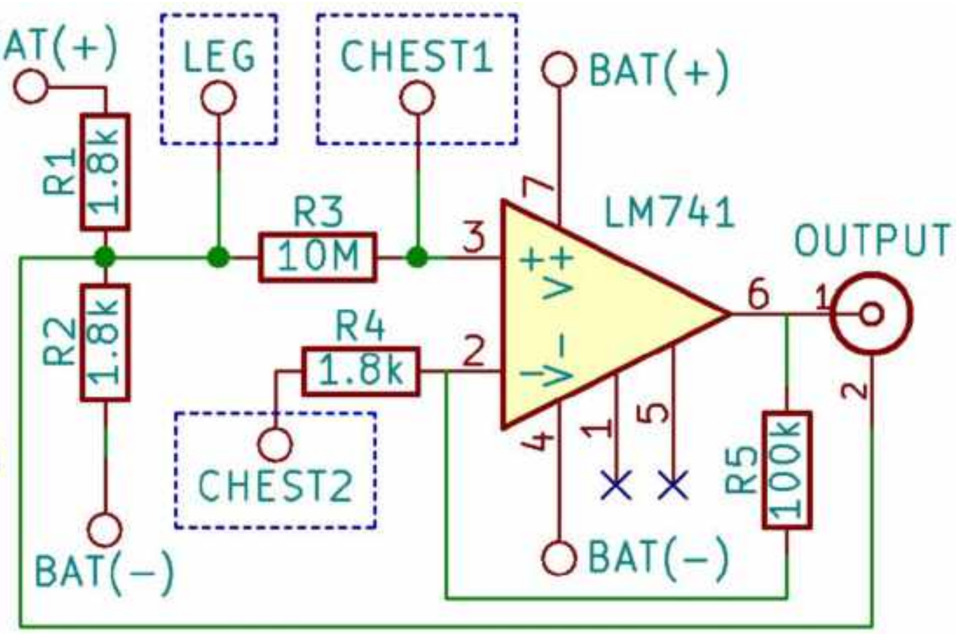
b. Technical Description :

- Analog Components : LM741 operational amplifier, 1.8 KΩ resistors, 100KΩ resistors, 10MΩ resistors, Male to Male jumper cables, TRS auxiliary cable, 9V Battery, ECG pads, ECG connectors.

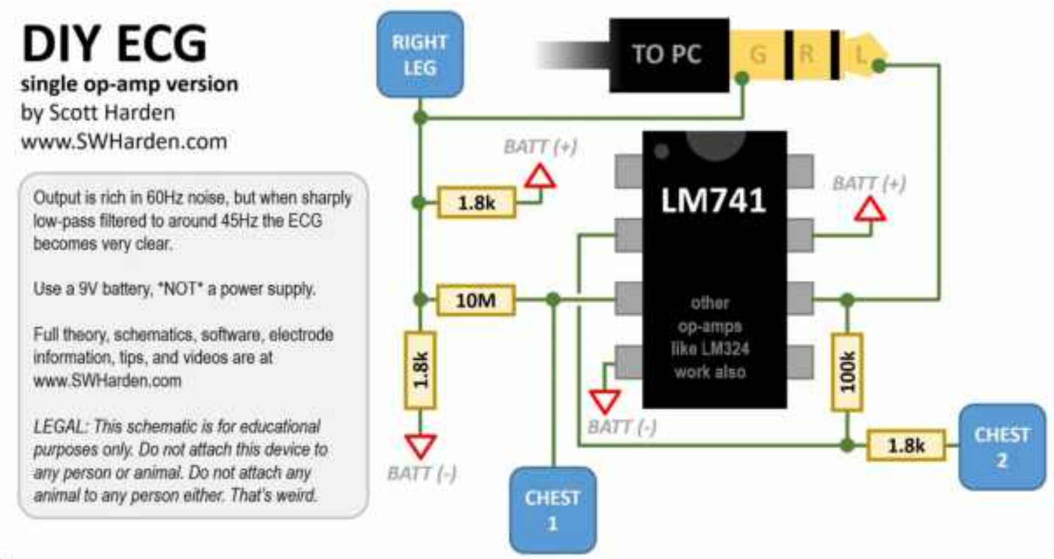
- Digital Components : MacBook Pro, PyCharm Professional IDE (Python)

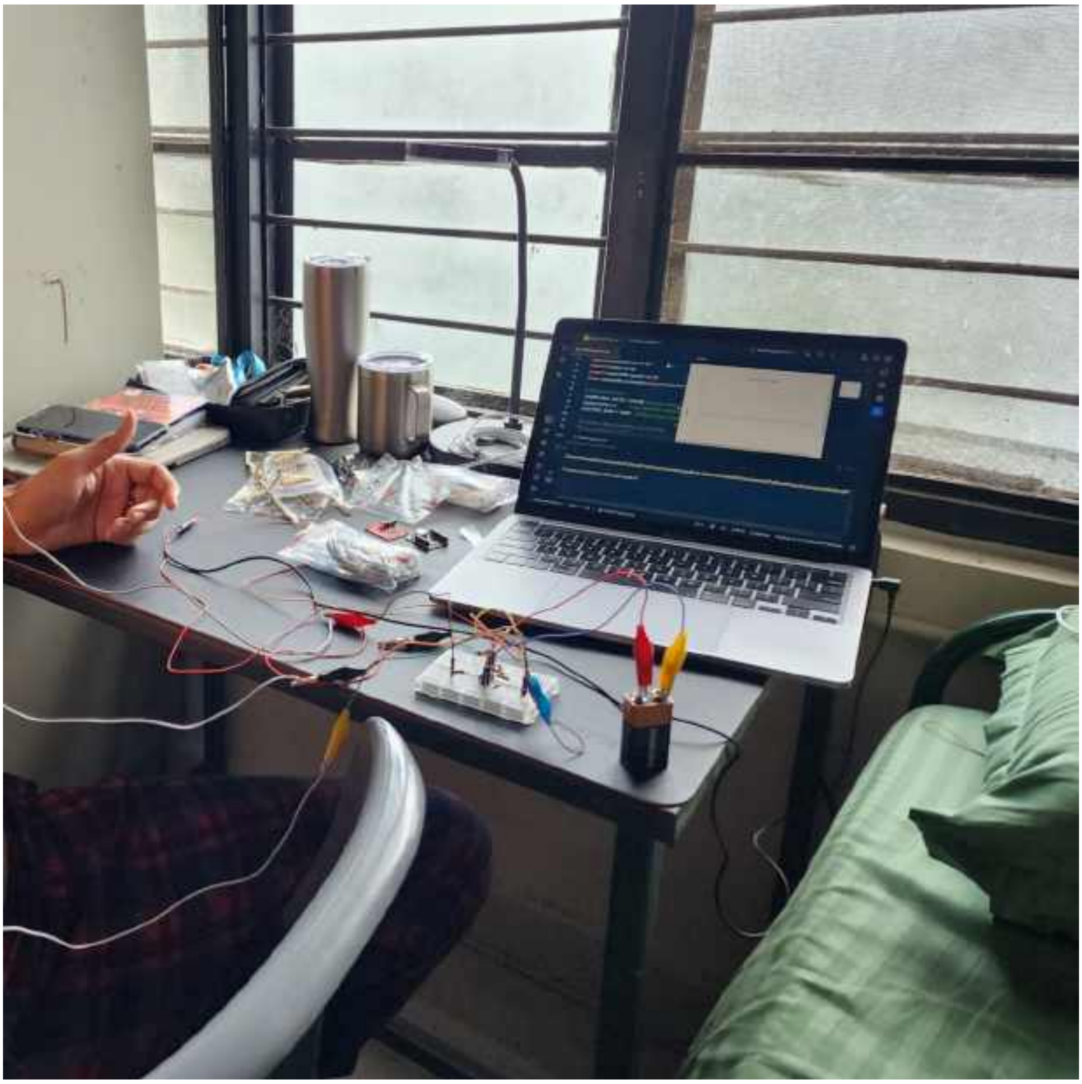
c. Design Process :

- We started out by connecting the resistors and the operational amplifier, according to the connections in the circuit diagram given below in a solderless bread board.



- After making the connections, we went on to solder the specific terminals of the circuit on to the G and L terminals of a TRS auxiliary cable (headphone cable). The other end of the jack was connected to a device, and a Python program was used to interpret this output as an input signal(Since we didn't have a TRRS cable, which is recognized as an input). The Python program processed the signal to produce the ECG waveform digitally. This method introduces potential noise and signal loss, as audio jacks are not designed for high-fidelity biomedical signal transfer.





d. Hardware and Software Tools used :

- Resistor Network :
  - 1.8k = Used for creating the voltage divider network for balancing the input signal from the body.
  - 100k = Used as a feedback resistor, from the output pin 6 to the inverting input pin 2, this is imperial for the control of the amplification power of the circuit.
  - 10M = This is used for the detection of the very weak signals, and are sent to the non – inverting pin 3.
- 9V Battery = Used for boosting the signal received from the input.
- Solderless Bread Board = Provided easy and sturdy connecting mechanism.
- Connecting Wires :
  - Single Core Copper Wires = Were used to solder and connect the ECG

connecters to the breadboard.

- Male to Male Jumper Cables = Used for the additional connections on the bread board.
- Crocodile Clip Cables = Used to connect the 9V battery to the 4 and 7 pins of the Operational amplifier.

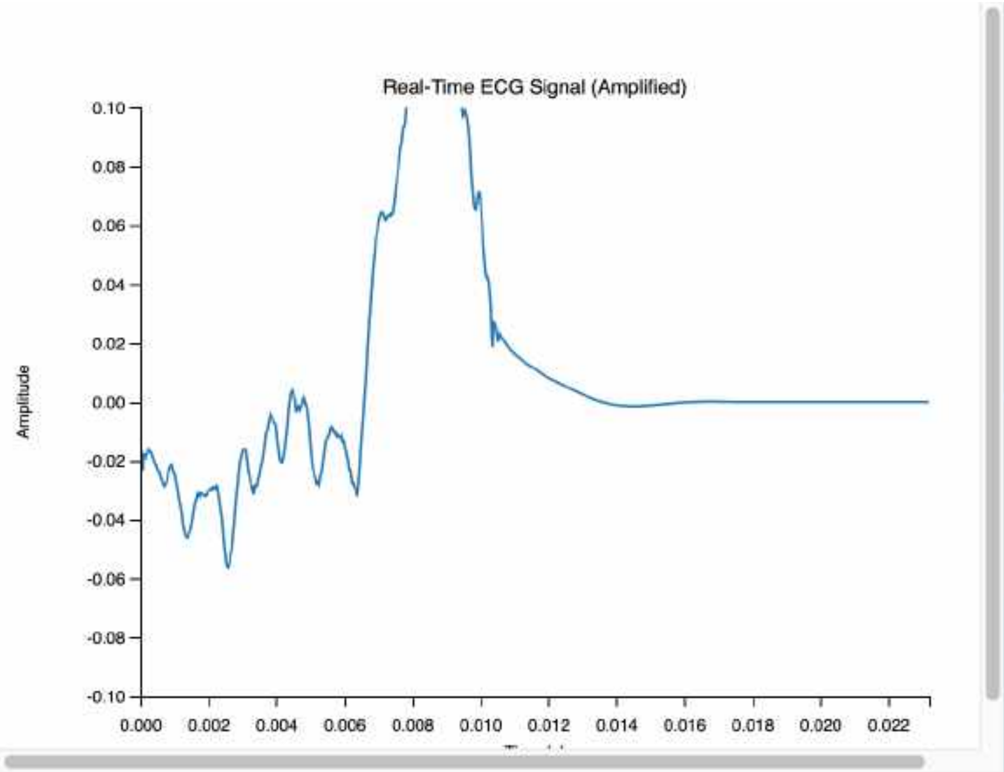
- TRS Auxiliary Cable = This cable was used to transfer the received data to be further analyzed by the help of the python program. One end was soldered onto the circuit terminals and the other end was plugged into the audio jack of the computer.
- PyCharm Professional IDE
- Specialized Python Code :

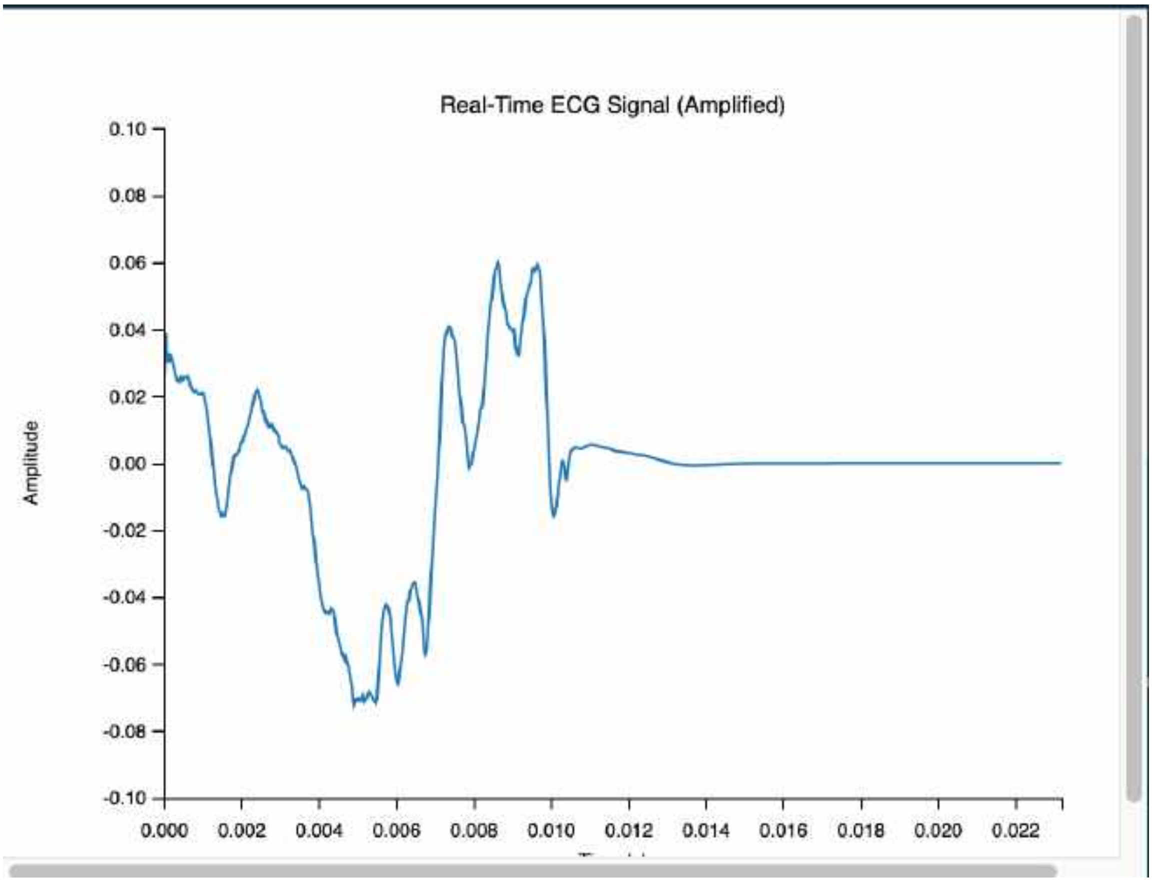
```
import sounddevice as sd
import numpy as np
import matplotlib.pyplot as plt
from matplotlib.animation import FuncAnimation

# Parameters
SAMPLING_RATE = 44100  # Audio sampling rate (Hz)
DURATION = 2  # Duration for capturing (seconds)
BUFFER_SIZE = 1024  # Size of each buffer for live plotting
AMPLIFICATION_FACTOR = 100  # Increase to amplify weak signals further
AUDIO_DEVICE_INDEX = None  # Default input device

# Create figure and axis for plotting
fig, ax = plt.subplots()
x_data = np.arange(0, BUFFER_SIZE) / SAMPLING_RATE  # Time axis (seconds)
y_data = np.zeros(BUFFER_SIZE)
line, = ax.plot(x_data, y_data)

# Initialize plot settings
ax.set_xlim(0, BUFFER_SIZE / SAMPLING_RATE)
ax.set_ylim(-1, 1)  # Initial Y-axis limits; will auto-adjust
ax.set_title("Real-Time ECG Signal (Amplified)")
ax.set_xlabel("Time (s)")
ax.set_ylabel("Amplitude")


# Function to update the plot
def update_plot(frame):
    global y_data
    # Capture audio data from input device
    audio_chunk = sd.rec(BUFFER_SIZE, samplerate=SAMPLING_RATE,
channels=1, dtype='float32', device=AUDIO_DEVICE_INDEX)
    sd.wait()  # Wait until recording is complete
```

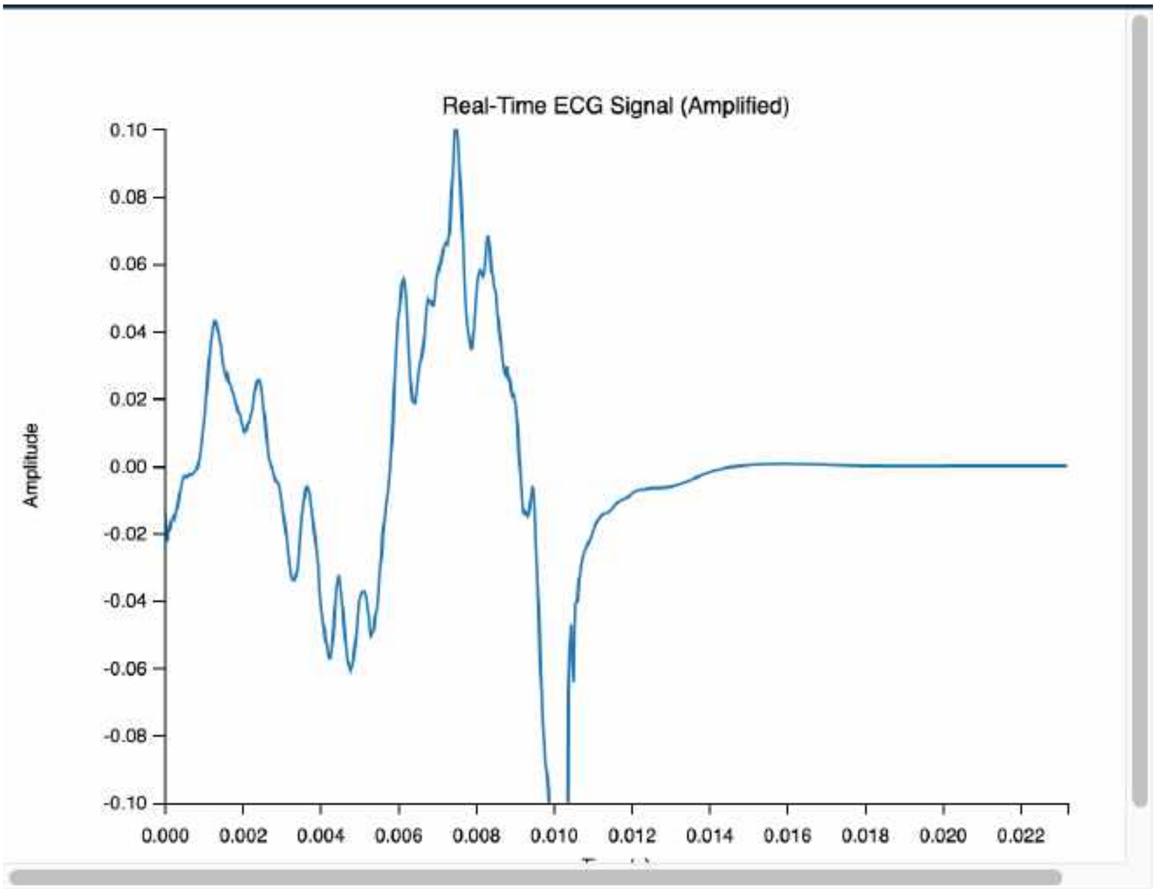
```
    # Amplify the signal
    y_data = audio_chunk.flatten() * AMPLIFICATION_FACTOR
    line.set_ydata(y_data)  # Update line with new data

    # Dynamically adjust the y-limits based on data
    ax.set_ylim(np.min(y_data) - 0.1, np.max(y_data) + 0.1)

    # Debug: print a small portion of the data to confirm signal
    print("Audio chunk data (first 10 samples):", y_data[:10])
    return line,


# Run animation with frame caching turned off
ani = FuncAnimation(fig, update_plot, blit=True, interval=50,
cache_frame_data=False)
plt.show()
```

e. Result Analysis :

- The device was tested extensively on all the group members.
- The resultant plot contained identifiable peaks which showed the systole phase of the cycle.
- The following plots were obtained :




Real-Time ECG Signal (Amplified)
Amplitude
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0.016
0.018
0.020
0.022


Real-Time ECG Signal (Amplified)
Amplitude
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
0.000
0.002
0.004
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0.014
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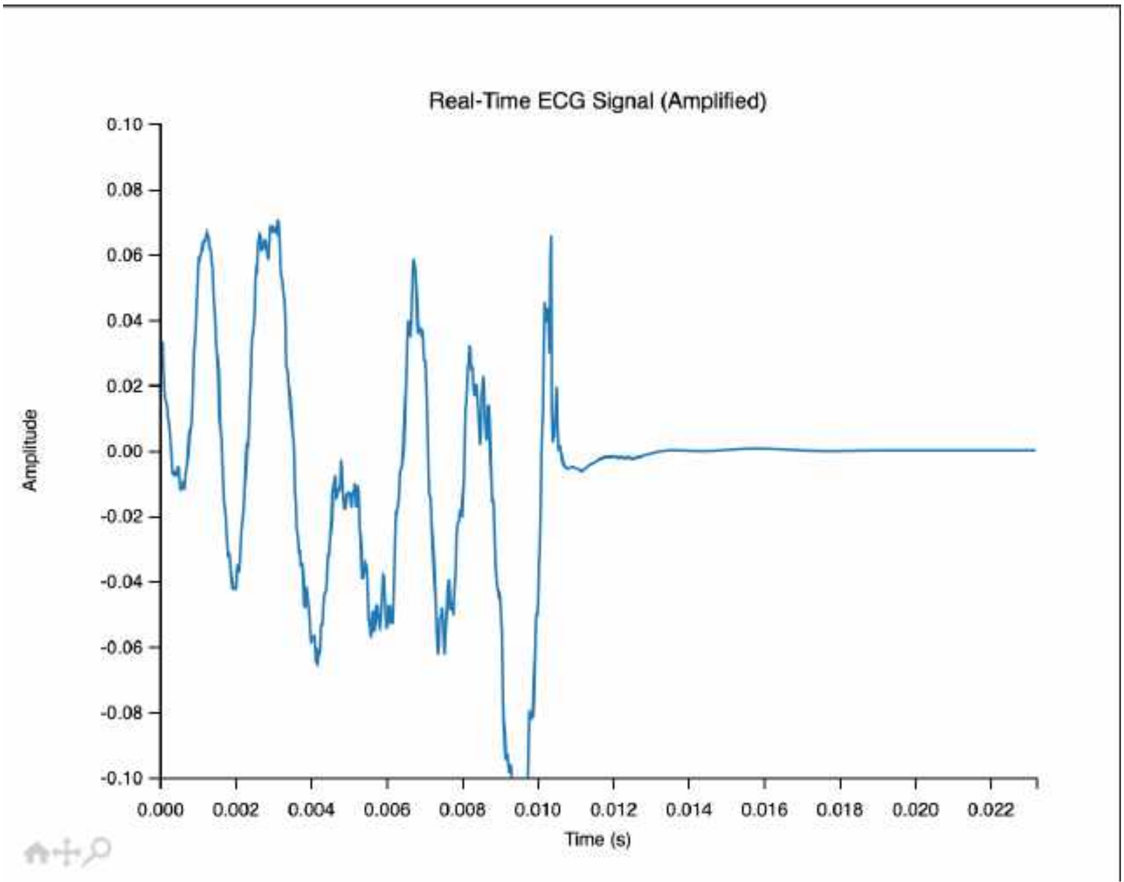
0.018
0.020
0.022


Real-Time ECG Signal (Amplified)
Amplitude
Time (s)
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
0.000
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0.014
0.016
0.018
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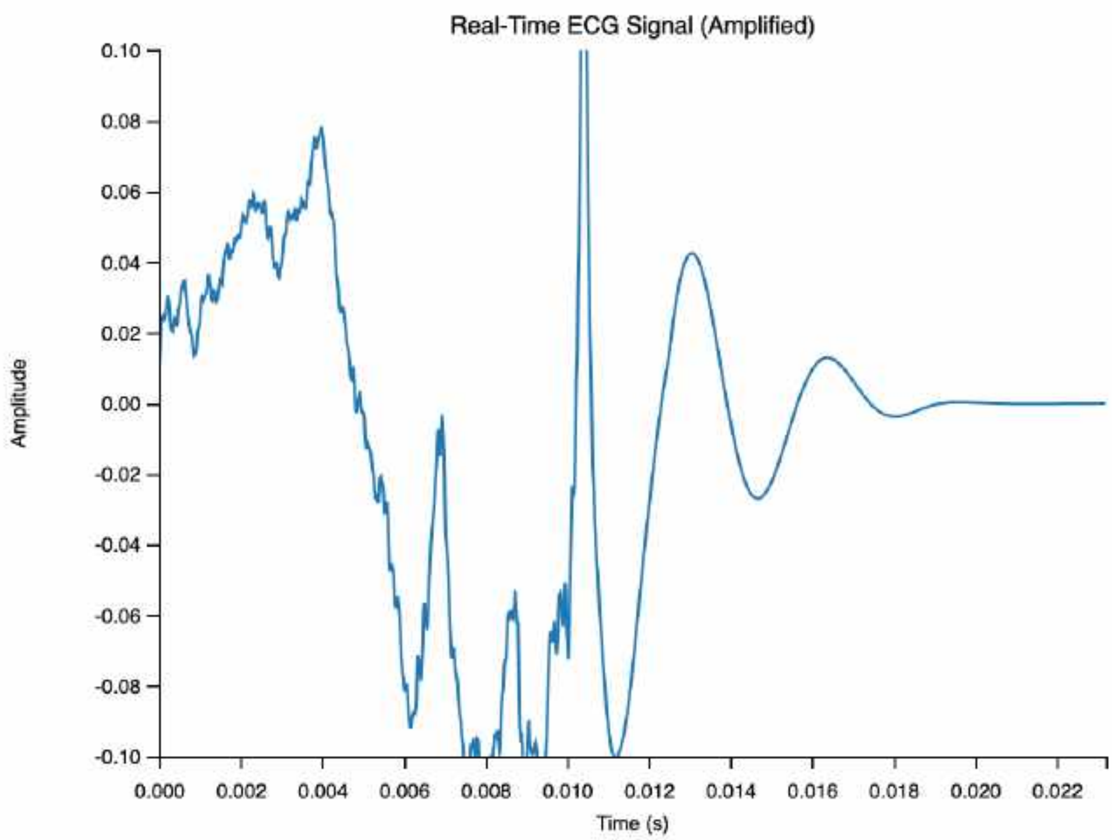
0.022


Real-Time ECG Signal (Amplified)
Amplitude
Time (s)
0.10
0.08
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0.00
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-0.04
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-0.08
-0.10
0.000
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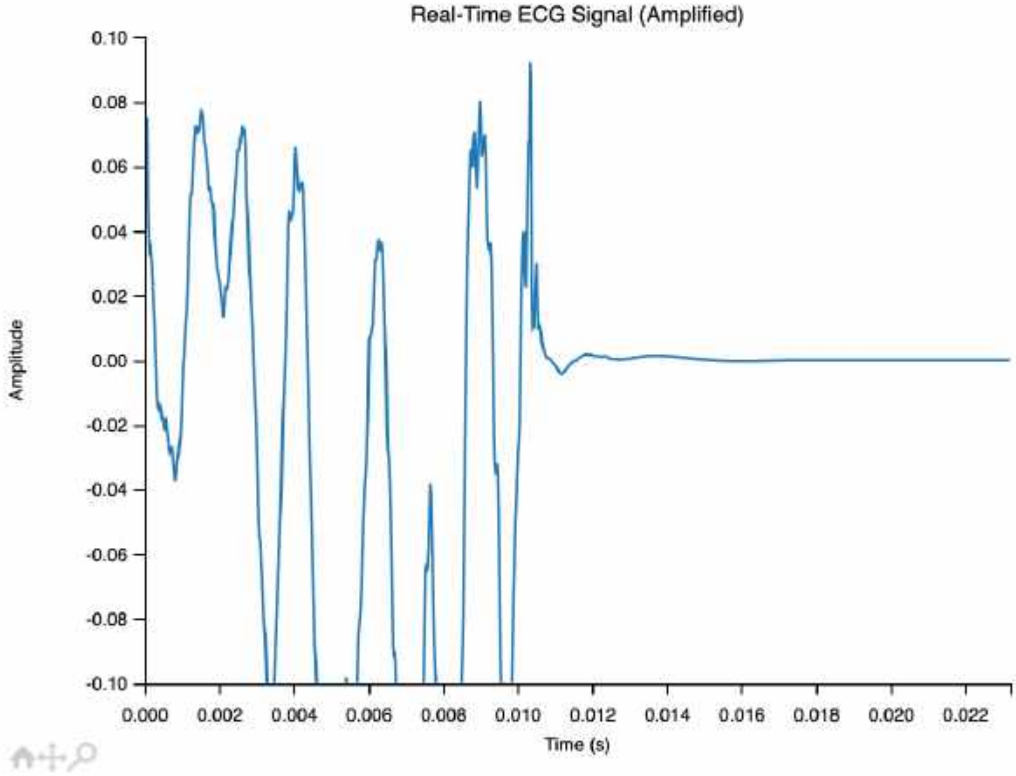

- The graphs obtained contained high amount of noise, due to the lack of digital conditioning, analog filters and operational human errors.
- This circuit is not an example of a live ECG and only has a capture of 2 seconds, due to limited resources.
- The gain of this circuit is approximately 56.56. This amplification may not be sufficient for raw ECG signals, as typical ECG circuits need a gain between 500-1000. Thus, not allowing the peaks of the ECG to be clearly visible above the noise.

f. Conclusions :

This project successfully demonstrates the implementation of a rudimentary electrocardiogram using the Operational Amplifier LM741. The designed model provides a convenient and inexpensive way for capturing and amplifying heart signals, enabling the visualization of ECG waveforms. It serves as an educational tool to understand the basics of biomedical signal processing and showcases the potential for low-cost, analog-based medical instrumentation.

g. Future Improvements:

- **Enhanced Noise Reduction and Signal Conditioning:**
    - Digital Signal Processing (DSP): Incorporate a microcontroller or a digital signal processor to apply real-time filtering and noise reduction algorithms, such as moving average or adaptive filters.
    - Improved Analog Filters: Add high-quality low-pass and high-pass filters to the circuit to minimize noise and baseline wander.
    - Shielded Components: Use shielded cables and properly grounded connections to reduce external electromagnetic interference.
- **Real-Time and Continuous Data Capture:**
    - Extended Recording Capability: Integrate a microcontroller with an analog-to-digital converter (ADC) to enable continuous signal acquisition and storage. This would allow for real-time ECG monitoring and eliminate the current 2-second limitation.
    - Data Transmission: Include a wireless module (e.g., Bluetooth) for real-time data transmission to a computer or smartphone for further processing.
- **Increased Gain for Better Signal Clarity:**
    - Higher Gain Amplification: Replace the LM741 op-amp with a more suitable instrumentation amplifier (e.g., AD620 or INA128) that provides higher gain and better common-mode noise rejection.
    - Adjustable Gain: Design the circuit with a variable resistor (potentiometer) to dynamically adjust the gain between 500-1000 for optimal signal clarity.
- **User-Friendly Interface and Display:**
    - Graphical User Interface (GUI): Develop a Python-based GUI for real-time ECG visualization, including features for zooming and analyzing specific parts of the waveform.
    - Live Monitoring: Implement real-time waveform updates to

observe the heart's activity continuously.

h. References:

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