# Wearable Analog Synthesizer

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## Abstract

The surface electromyogram (sEMG)-controlled audio synthesizer are wearable sleeves that make real time effects on sound output through selected arm movements and hand gestures, as outlined in the “List of Movements” section. The sleeve allows users to select different waveforms, control amplitude and frequency, and add a sustaining effect to the audio, creating a vibrato effect. Together, these features make the device a flexible, non-restrictive musical instrument.

To achieve this functionality, we used two sEMG sensors and accelerometer (xyz-axis) data from a 9DOF sensor placed on key forearm and upper arm muscles (see images A & B) to collect training data. This data was used to train a machine learning model that maps muscle activity to specific selector commands. Inside the sleeve is an ESP32 chip paired with a calibration system used to normalize amplitude output of muscle movements, making the system flexible to different users. The sensors interface with ESP32 chips, which transmit data wirelessly via Bluetooth Light. The server ESP32 chip directly feeds the control voltages to the analog circuit, allowing the user to modify the waveform in real time. More details on the analog circuit are provided in the Hardware section.

## List of Movements: A “How-To” Use Guide

| Hand or Arm Movement | Left Arm - Hand & Forearm Orientation | Right Arm - Hand & Forearm Orientation |
|---|---|---|
| Arm | Amplitude (volume) → **Raise motion:** Hold your arm at a 90 degree angle with your palm facing up. Bend your elbow and raise your forearm up until your forearm is perpendicular to the ground. | Pitch → **Raise motion:** Hold your arm at a 90 degree angle with your palm facing up. your forearm is perpendicular to the ground. |
| Hand | Waveform setting: Sawtooth wave → **Extend motion:** Hold your arm at a 90 degree angle with your palm facing up. Bend your wrist backwards until your palm is facing away from you. | Waveform setting: AM Modulation (Hilbert Mixer) → **Extend motion:** Hold your arm at a 90 degree angle with your palm facing up. Bend your wrist backwards until your palm is facing away from you. |
| Hand | Waveform setting: Sine Wave → **Fist motion:** Close your hand into a fist. Keep your arm forearm facing the ceiling. | Sustain (vibrato effect): **Fist Motion:** Close your hand into a fist. Keep your forearm facing the ceiling. |
| Hand | Waveform setting: Triangle wave → **Flex Motion:** Hold your arm at a 90 degree angle with your palm facing up. Use your wrist to raise your hand until your palm is upright, facing your face. | |

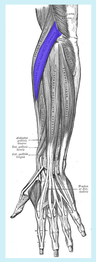
*Note: Any arm movement corresponds to the accelerometer from the 9DOF sensor, any hand movement corresponds to the EMG sensor.

## Device


C) Velcro based for an all-size fit. Inside of the sleeve is the accelerometer, a calibration button (with LED indication), an ESP32 chip, an EMG sensor that will make contact with the user’s skin and a three different batteries of various voltages to power the sleeve.

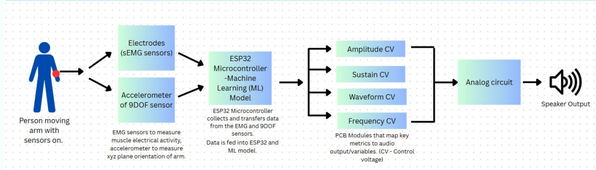
## Supporting Images

A) Flexor Digitorum Profundus - The inner muscle group of arm. Palms facing down.

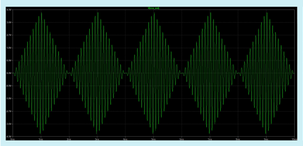


B) Extensor carpi radialis valgus longus - The outer muscle group of the arm. Palm facing down.

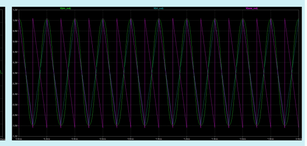
## General Block Diagram



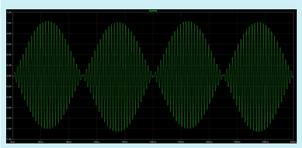

## Analog Waveforms



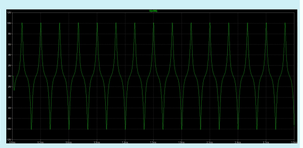
VCA



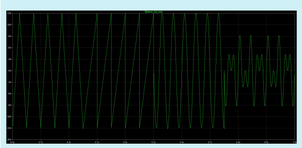
Waveform Reshaper



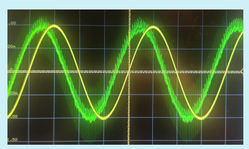
Gilbert Mixer



Linear -> Expo Converter



Waveform Selector



Sustain

## Hardware Description

The synthesizer is a wearable sleeve equipped with MyoWare 2.0 sensors that detect muscle activity from the forearm and upper arm. A 9-degree-of-freedom (9DOF) sensor provides real-time tracking of arm orientation using accelerometer data (x, y, z axes). Sensor data is wirelessly transmitted via ESP32 microcontrollers mounted on custom PCBs. The output of the server ESP generates CVs that interact with a modular analog circuit responsible for generating and modifying audio waveforms. Users can select different waveform types because of MUXes integrated in the analog circuit. Users can control frequency and amplitude by raising their forearm, as the acceleration data is mapped to control voltages. More details about the circuitry components can be found in its block diagram below. The output of the analog circuitry is wired to a speaker.

## Software Description

The software side handles data acquisition, wireless transmission, and gesture recognition. Using C++ based code developed in Visual Studio Code with the PlatformIO extension, ESP32 microcontrollers collect real-time signals from EMG sensors and a 9DOF sensor (accelerometer only). These signals are transmitted over Bluetooth to a server ESP. A machine learning model is trained on this data to associate specific combinations of muscle activity and arm movement with predefined hand gestures. Once trained, the model classifies incoming data in real time and outputs corresponding control signals. These signals determine waveform selection, pitch, and amplitude within the analog synthesizer circuit. A calibration script ensures reliable performance across different users and usage sessions.

## Analog Block Diagram