Animatronics
Overview Document

By: Jim Schrempp and Bob Glicksman; v1.1, 12/23/2025

NOTICE: Use of this document is subject to the terms of use described in the document "Terms_of_Use_License_and_Disclaimer" that is included in this release package. This document can be found at:

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Terms_of_Use_License_and_Disclaimer.pdf

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DOCUMENT OVERVIEW.

This document provides an overview of the Team Practical Projects' *Animatronic Head* project. The *Animatronic Head* is a complex project. A complete description of this project is contained in a number of documents, each detailing a specific aspect of the design. This document contains a high level overview of the project and should be the "first read" document serving as an introductory overview of the project.

PROJECT DESCRIPTION.

Project Overview.

The *Animatronic Head* project was designed and developed to explore various aspects of animatronic interaction with humans. The *Animatronic Head* (Head) consists of:

- A "Brain". An 8x8 matrix Time-of-Flight (TOF) sensor provides the Head with a crude, three dimensional view of its nearby surroundings. "Brain" software processes this information to determine when a visitor is inside of its relevant field of view and what the visitor is doing, so that the Head can interact with him/her.

- The "Eyes". A six servo eye mechanism provides complex movements of an animatronic set of eyes. The mechanism allows independent software control of upper and lower eyelids on each eye as well as coordinated vertical and horizontal movement of the left and right eyeballs. The software has been designed in a programmable, hierarchical manner that provides an infrastructure to experiment with complex and interactive eye movement scenarios.

- The "Mouth". A simple, single servo mechanism moves the jaw to simulate mouth movements when speaking. The "Mouth" electronics can play pre-recorded MP3 voice clips though a small loudspeaker. On-board analog signal processing circuitry extracts the "envelope" of the spoken voice clip and software digital processing of this envelope waveform moves the "Mouth" servo in synchronism with the audio in order to create the illusion that the Head is speaking to the visitor.

The overall structural and mechanical design of the Animatronic Head was developed with experimentation and iteration in mind. Separate microcontroller-based electronics are provided for the "Brain/Eyes" and for the "Mouth" so that these components can be developed and experimented with independently. These two electronic elements are interconnected by a

Particle[1] Cloud-based publish/subscribe mechanism that allows the entire project to be interconnected and synchronized while still being extensible for future experimentation and use.

The Structure.

In order to make this project suitable for experimentation and evolution, a flexible frame was created in 2D CAD and the pieces cut out on a laser cutter. The basic frame structure is shown in figure 1.

Figure 1. Frame Design.

Figure 2 provides a side overview of the assembled project. Two identical sides, a base, a back and a top handle are glued together to form a rigid, yet open frame that mounts all of the mechanical and electronic components. Two shelves are used to mount the major electronic and mechanical components. The shelves can be mounted at adjustable heights in order to precisely align the mechanisms with the 3D printed face. Adjustment is provided using screws and wingnuts.

[1] Particle.io

The 3D printed face consists of a crown, the eyes, and the mouth. Each of these 3D printed face pieces is mounted to the frame using magnets that are glued to 3D printed mounting ears and to the back of the face piece. The mounting ears can be flexibly placed on the frame using screws and wingnuts.

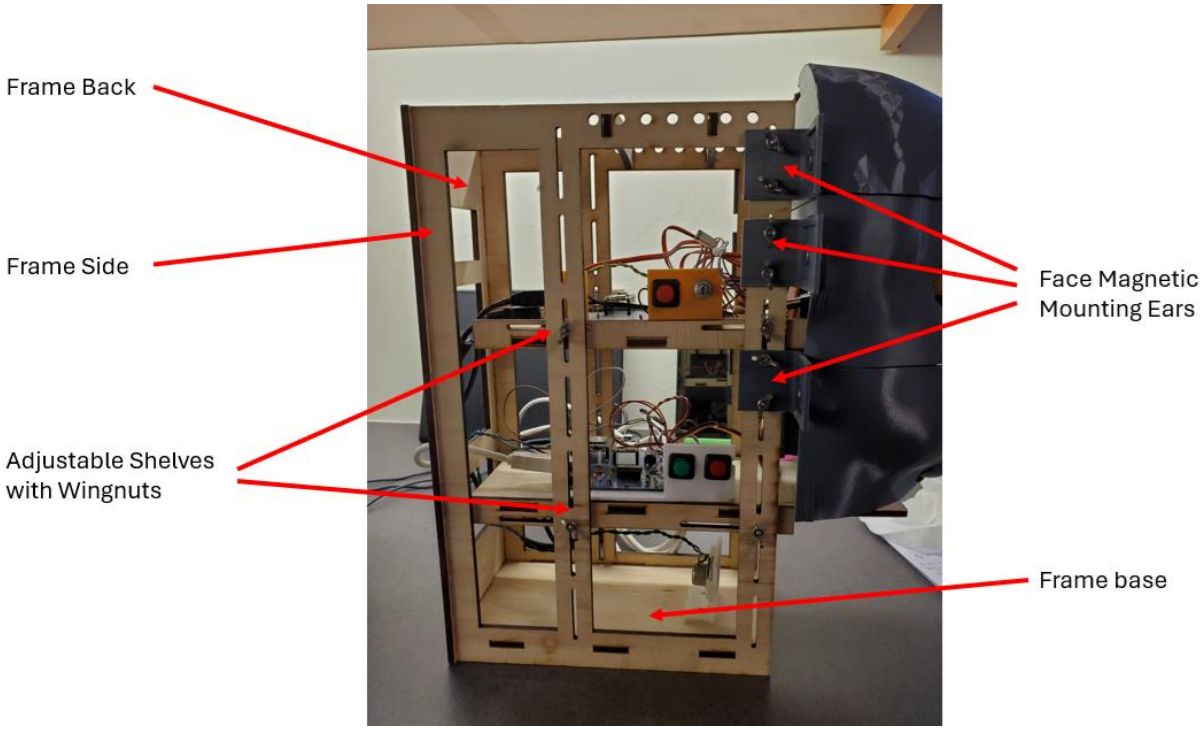

Figure 2. Frame Fully Assembled.

The upper shelf holds the 3D printed eye mechanism, an electronic servo control board, and a custom printed circuit board that holds a Particle Photon 1 microcontroller. The second, lower shelf holds the Mouth mechanism and mouth electronics printed circuit board. The mouth printed circuit board also uses a Particle Photon 1 microcontroller and provides the MP3 audio player module and custom designed analog signal processing circuitry. See figures 3 and 4 for a close-up view of these components.

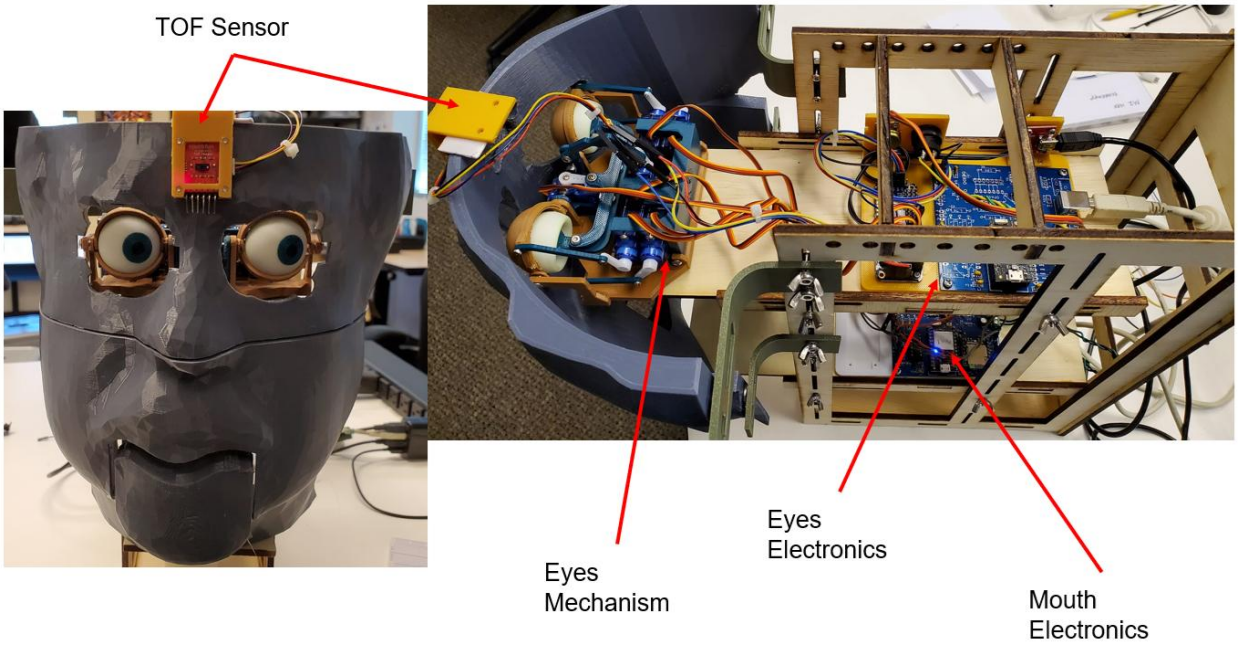

Figure 3. Frame Top View – Brain/Eyes.

Figure 4. Mouth Mechanism.

The structural and mechanical aspects and open-source CAD files for the *Animatronic Head* are described further in the document:

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronic%20Head%20Structural-Mechanical%20Hardware%20Document.pdf

The Brain.

The “Brain” of the Animatronic Head uses an 8 x 8 matrix optical time-of-flight (TOF) sensor to gather information about the environment:

https://www.sparkfun.com/sparkfun-qwiic-mini-tof-imager-vl53l5cx.html

A larger but easier to experiment with version of the same sensor can also be used:

https://www.sparkfun.com/sparkfun-qwiic-tof-imager-vl53l5cx.html

Both of these modules use a VL53L5CX TOF sensor from ST Electronics. Each sensor of the 8 x 8 sensor array provides a precise distance measurement to a corresponding object within the sensor’s field of view. The VL53L5CX can provide a new 8 x 8 frame of measurement data up to 15 times per second, over an I2C (Qwiic) bus connection. Connection of the Photon 1 microcontroller custom printed circuit board (PCB) to a 16 channel servo control board and to this sensor is shown in figure 5, below.

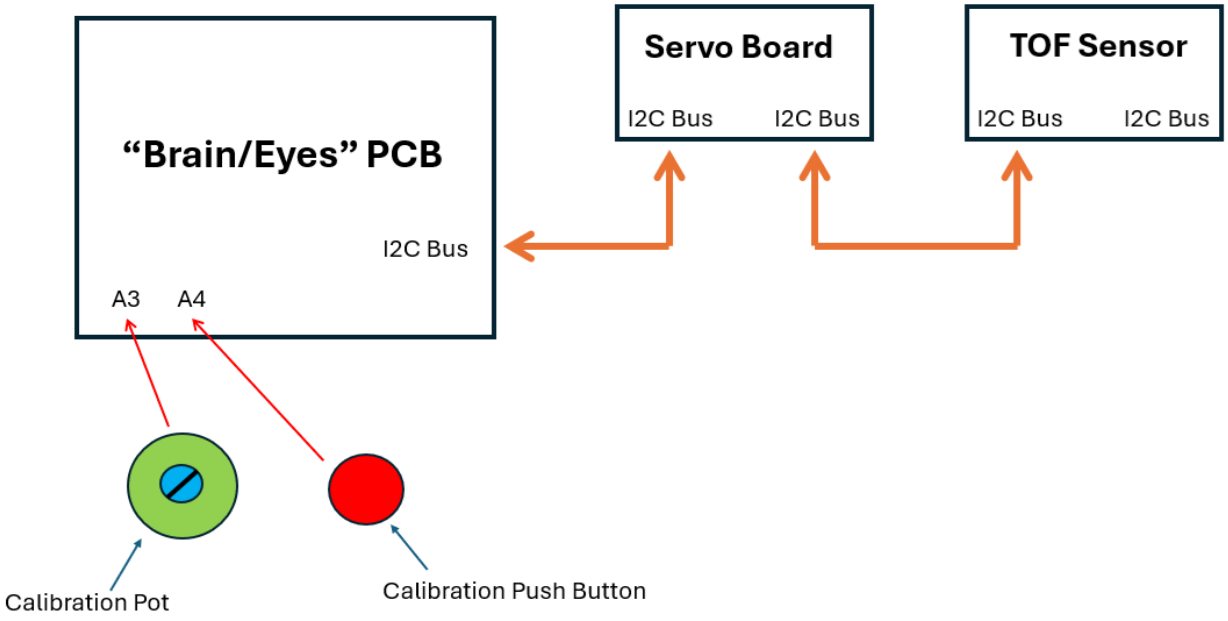

Figure 5. Brain/Eyes Electronics.

Software on the “Brain/Eyes” microcontroller reads frames of sensor data continuously. When the electronics are initialized, the sensor “scene” is calibrated for an empty room. This

calibration provides a “picture” of the empty room – where static “background” objects are located, so that future human movement in front of these objects can be determined. The calibration also limits the scope of the sensor “Brain” processing to approximately 2 meters in front of the Head. The Brain will not respond to anything further away than this.

Experimentation with this sensor has shown that its output is “noisy”. Both background optical noise and multi-path “noise” seem to be the culprits. In order for the “Brain” to determine what is inside of its sensing envelope and what is closest to the Head, both spatial and temporal processing filters are applied (in software) to the regular frames of data from the sensor.

Filtered frames of distance measurements from the sensor are processed (in software) to determine the center point of whatever is closest to the Head inside of its field of view, but in front of its “empty room” calibration. This information is used to move the eyes so that they track a visitor who enters the Head’s field of view. The brain software also processes this information to publish various “events” of significance to the Particle Cloud:

- Person first enters the field of view.
- Person approaches the Head too closely
- Person leaves the field of view after engagement with the Head
- Person leaves the field of view too soon after arrival (too soon for engagement with the Head).

These events are subscribed to by the “Eyes” Photon 1 processor and are used to play appropriate audio clips over the Mouth loudspeaker.

The “Brain” processing, and how it moves the “Eyes”, is further described in the document:

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronics%20Brain%20Document.pdf

The electronic hardware used on the Head is further described in the document:

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronic%20Head%20Electronic%20Hardware%20Document.pdf

The Eyes.

The eyes mechanism itself is an intricate assembly consisting of six hobby servos and an integrated set of 3D printed parts. We adapted the following excellent mechanism from Will Cogly’s design on the Internet; see:

https://www.instructables.com/Simplified-3D-Printed-Animatronic-Dual-Eye-Mechani/

The maker, Will Cogley, is incredibly inventive. His YouTube channel has a lot of amazing things:

https://www.youtube.com/channel/UCkUD_8b1JoTL2ipOVtxfNKw

We modified a few of the eye mechanism parts, see:

https://github.com/TeamPracticalProjects/Animatronics/tree/main/Mechanical/EyeMech

Owing to pin limitations on the Photon 1 microcontroller, we used an external 16 channel servo module to control the 6 servos of this eye mechanism; see:

https://www.adafruit.com/product/815

This module connects to the “Brain/Eyes” PCB using the I2C bus; see figure 5, above.

The “Brain/Eyes” Photon 1 software has been designed for experimentation with eye movement effects. To this extent, a “software stack” has been developed that provides a hierarchical means of creating complex eye movements:

- Basic movements of each servo: position and speed of movement to a new position are encapsulated into objects of the animateServo class.

- Coordinated movements of various servos into a scene (e.g. blink the eyes) incorporate animateServo objects into instances of the animatePuppet class.

- Time sequenced lists of animatePuppet objects create complex scenarios; e.g. a “sleepy dog” effect whose eyes are normally closed, then open halfway, the eyes pan left/right to survey the scene, and then close again when the dog goes back to sleep.

These eye movement effects can be “standalone” or linked to “Brain” object tracking information. Both of these effect types are incorporated into the “Brain/Eye” software that is released as part of this project. See the following document for further information:

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronics%20Brain%20Document.pdf

The complex eye system requires calibration after the 3D printed mechanism is assembled. Special calibration software guides the user through the calibration process, using a potentiometer and pushbutton that are connected to the electronics PCB as shown in figure 5. A detailed description of the eyes control and the calibration process in the following document:

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronic%20Head%20Eye%20Mechanism%20Document.pdf

The Mouth.

The “Mouth” PCB contains a DFRobot DFPlayer mini MP3 player module:

https://www.dfrobot.com/product-1121.html

This module accepts a micro SD card and can play MP3 format audio clips through a small loudspeaker. Software on a Particle Photon 1 microcontroller on the “Mouth” PCB controls which clip to play in response to events that it subscribes to via the Particle Cloud. In the Animatronic Head project, these events are published by the “Brain/Eyes” electronics. However, the “Mouth” electronics are otherwise independent and can be deployed separately on other projects.

Connections to the “Mouth” PCB are shown in figure 6. In addition to the Photon 1 and the mini MP3 player, the “Mouth” PCB contains custom designed analog signal processing circuitry. This circuitry conditions the analog signal output from the mini MP3 player and then extracts the “envelope” of the signal via AM demodulation. The envelope signal is bandlimited to about 40 Hz and then sampled by the Photon 1 A/D converter every 10 milliseconds[2].

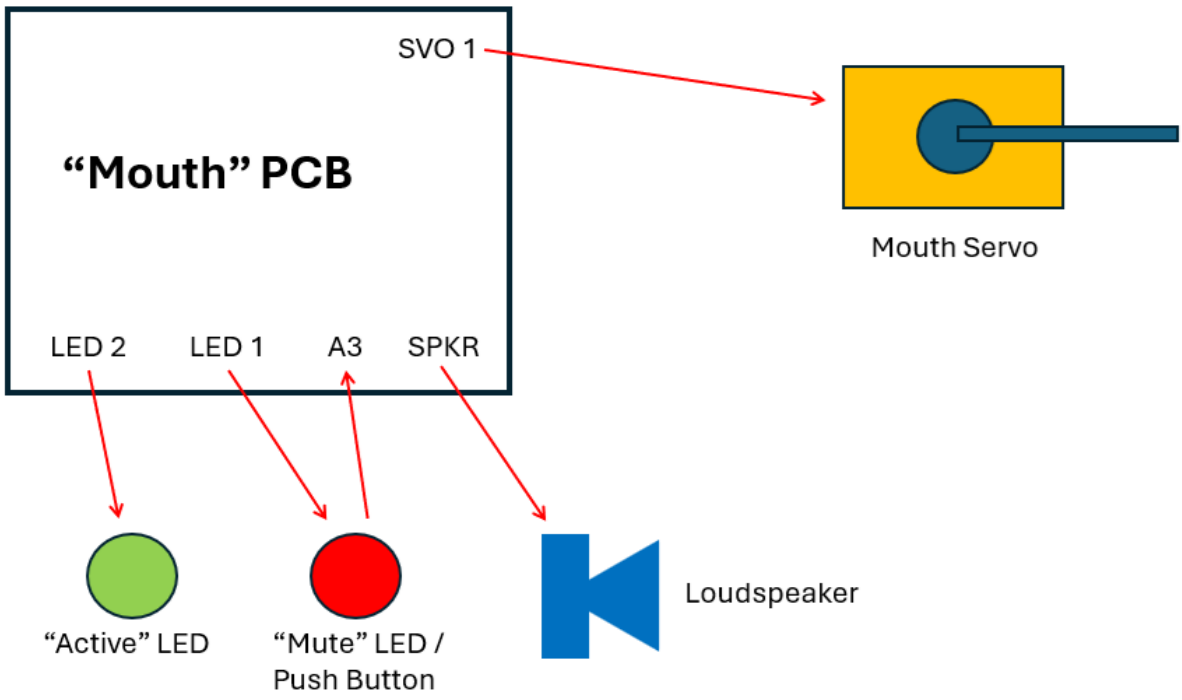

Figure 6. Mouth Electronics.

[2] This 100 Hz sampling rate exceeds the Nyquist criterion for the 40 Hz bandlimited envelope signal.

These analog/digital samples are then processed in software through a digital signal processing chain that ultimately drives the servo that moves the mouth in synchronism with the audio clip being played. The digital signal processing chain is designed to allow for experimentation toward providing the most convincing movement of the “Mouth”.

The “Mouth” electronics and the theory of operation of the analog signal processing circuitry are described further in the document:

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronic%20Head%20Electronic%20Hardware%20Document.pdf

The Photon 1 software contains tools for experimenting with settings for the software digital processing chain. The user can interact with these settings using the Particle Console. The best settings for presentation of each pre-recorded voice clip are stored with the software in an included file. When clips are triggered to be played back, they are then played with optimal volume and mouth movement settings.

The “Mouth” software allows several “personalities” to be used with the Head. Each “personality” contains a set of one or more audio clips that are associated with a given Cloud event. When an event is received from the Cloud, a clip for that event within the selected “personality” is randomly chosen for playback. This mechanism allows the Head to be set up to play different clips in different voices depending upon the venue where the Head is being demonstrated.

A detailed description of the “Mouth” software, along with instructions for optimizing the processing chain for each recorded clip, is found in the document:

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronics_Mouth_Software_Description_Document.pdf

DOCUMENTATION TREE.

The *Animatronic Head* is a complex project. This Overview document only summarizes the technical aspects of the project. The Documents folder contains additional, more detailed descriptions of the structural, mechanical, electronic and software elements of the project. This section describes each of the files in the Documents folder. Many of these documents have been referenced earlier in this Overview.

Animatronic Head Structural-Mechanical Hardware Document.

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronic%20Head%20Structural-Mechanical%20Hardware%20Document.pdf

This document contains details of the overall structural and mechanical elements of the *Animatronic Head.* It contains detailed photos and drawings of the physical and mechanical aspects of the project. It also provides references to the CAD source files that are in the Mechanical folder in this repository.

Animatronic Head Electronic Hardware Document.

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronic%20Head%20Electronic%20Hardware%20Document.pdf

This document contains detailed descriptions of the electronic components and electronic interconnections of both the “Brain/Eye” electronic subsystem and the “Mouth” electronic subsystem. It describes the electronic design, theory of operation, and assembly of the custom electronic printed circuit boards used on this project and the interconnection of external modules and components to these circuit boards. It contains links to the open source electronic CAD and software files that are provided in this repository (in the Hardware and Software folders, respectively).

Animatronic Brain Document.

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronics%20Brain%20Document.pdf

This document provides a detailed description of the algorithms used to process data from the optical time-of-flight (TOF) sensor: determination and tracking of the closest object in its field of view and the generating of the events that are published to the Particle Cloud. It provides a detailed description of the hierarchical software structure that allows development of, and experimentation with, complex coordinated eye movements and effects. The document contains links to the open source software files that are provided in this repository (in the Software folder).

Animatronic Head Eye Mechanism Document.

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronic%20Head%20Eye%20Mechanism%20Document.pdf

This document provides a detailed description of the calibration and control of the complex, six servo eye mechanism. It guides the user through the special calibration procedure and software needed to calibrate a newly assembled mechanism and describes how to incorporate

the calibration data into the “Brain” software. The document contains links to the open source software files that are provided in this repository (in the Software folder).

Animatronics Mouth Software Description Document.

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronics_Mouth_Software_Description_Document.pdf

This document provides a detailed description of the digital software algorithms used to process sampled envelope data from the “Mouth” electronics hardware into movements of the mouth servo. It provides instructions for setting and monitoring the various processing settings that are available for experimentation with optimizing the mouth movement effects. The document contains links to the open source software files that are provided in this repository (in the Software folder).

Analog Processor V2 Analysis.

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Analog_Processor_V2_Analysis.pptx

This document is a PowerPoint slide deck that details the results of the design and simulation of the “Mouth” electronics analog signal processing circuitry. The simulation used LTSpice to provide time and frequency/phase domain data on a number of test data files that were created to verify the analog circuit design. The resulting waveforms are presented along with the *wave* files that were created to drive the simulated circuit in LTSpice. The audio test files themselves are included in the Data folder in this repository.

Jumper Settings for Personalities.

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Jumper_settings_for_personalities.txt

This very brief document lists the jumper settings for the “Mouth” personalities that are released in the Software and Data files in this repository.

CONTENTS OF THIS REPOSITORY.

The folder structure and contents of this GitHub repository are described in this section.

Root.

The Root folder contains this Overview document and the Terms of Use, License and Disclaimer document that you must read and agree to in order to use the information, designs, and source files contained in this GitHub repository; see:

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Terms_of_Use_License_and_Disclaimer.pdf

It also contains a photo of the Head, and the master README.md file for the project.

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Head.png

https://github.com/TeamPracticalProjects/Animatronics/blob/main/README.md

Data.

The Data folder contains wave (.wav) and MP3 (.mp3) format audio files that were used in the development, simulation, testing and deployment of the “Mouth” hardware and software signal processing chains. It also contains .png format photos of the simulation and test results of simulated analog circuit processing of audio files using LTSpice. The subfolder “SDCardMP3Folder” contains the MP3 format voice clip files that on the microSD card that is released with this project:

https://github.com/TeamPracticalProjects/Animatronics/tree/main/Data/SDCardMP3Folder

Documents.

The Documents folder contains the detailed documentation for this project. See the “Documentation Tree” section of this document for details.

Hardware.

The Hardware folder contains details of the hardware design for the electronic portions of this project. It contains Cadsoft Eagle electronic CAD files for the common printed circuit board that is used for both the “Brain/Eyes” PCB and the “Mouth” PCB:

https://github.com/TeamPracticalProjects/Animatronics/tree/main/Hardware/Eagle_Files

This folder also contains data sheets, manuals and other information related to the electronic components used in this project.

Legacy-NotPartOfRelease.

This folder contains some Particle Photon 1 test software that was used to determine how to operate the Mini MP3 player correctly and to couple the sampled envelope data to the mouth servo via various software processing steps. The files in this folder are NOT part of the released project but are retained for legacy research purposes.

Mechanical.

This folder contains 2D and 3D mechanical CAD files for building the structural and mechanical mounting pieces for this project. Detailed descriptions and references to these CAD files are contained in the document:

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronic%20Head%20Structural-Mechanical%20Hardware%20Document.pdf

Software/Photonfirmware.

This folder contains source code files for this project, along with some legacy code that is not part of the formal release. The following subfolders contain the release software:

https://github.com/TeamPracticalProjects/Animatronics/tree/main/Software/Photonfirmware/AnimatronicEyesCalibration

Source code for the calibration software that is used to calibrate the eyes servo mechanism. See the following document for details:

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronic%20Head%20Eye%20Mechanism%20Document.pdf

https://github.com/TeamPracticalProjects/Animatronics/tree/main/Software/Photonfirmware/AnimatronicEyesTest

Source code for the “Brain/Eyes” software. See the following document for details:

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronics%20Brain%20Document.pdf

https://github.com/TeamPracticalProjects/Animatronics/tree/main/Software/Photonfirmware/AnimatronicMouthDemo

Source code for the “Mouth” software. See the following document for details:

https://github.com/TeamPracticalProjects/Animatronics/blob/main/Documents/Animatronics_Mouth_Software_Description_Document.pdf

The remaining subdirectories are legacies of the development process and do not contain any relevant files.