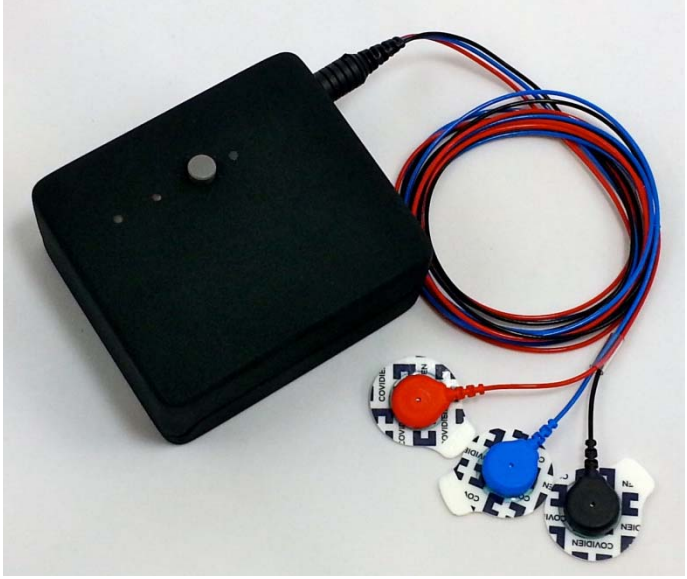


Muscle Mouse

The First Electromyography Bluetooth Mouse

Brian E Kaminski

FEATURES

- 3rd generation Muscle Sensor
- Bluetooth Technology
- Arduino Microcontroller
- 3D Printed Enclosure
- Powered by 6 AAA Batteries

APPLICATIONS

- Occupational/Physical Therapy
- Disabled Gaming
- In/out Patient Entertainment
- Strength Training
- Return To Duty Decision Tool
- Research Tool

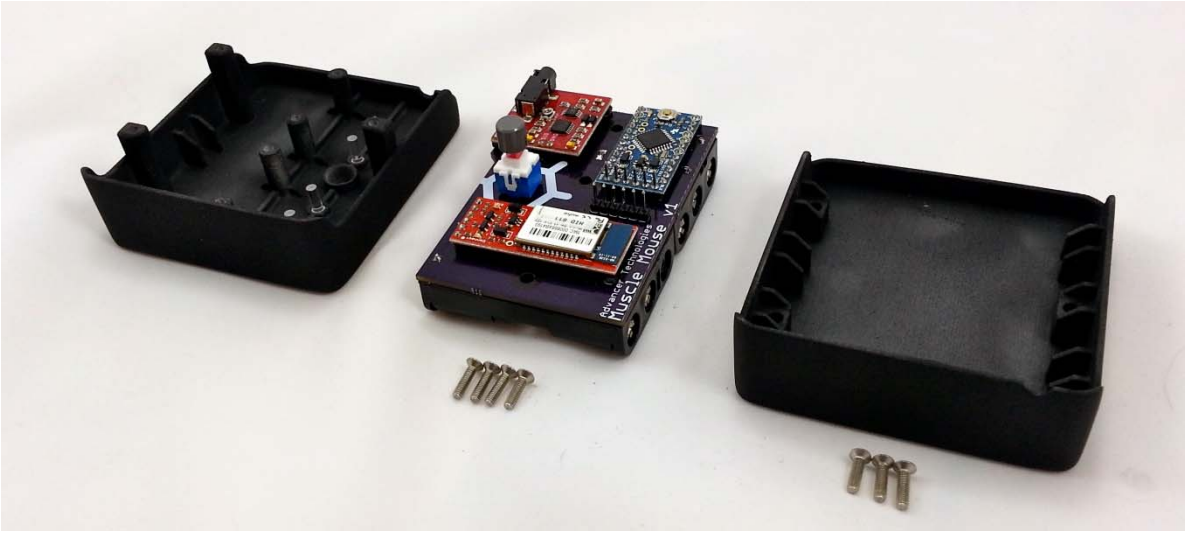
What is Electromyography?

Measuring muscle activation via electric potential, referred to as electromyography (EMG), has traditionally been used for medical research and diagnosis of neuromuscular disorders. However, with the advent of ever shrinking yet more powerful microcontrollers and integrated circuits, EMG circuits and sensors have found their way into prosthetics, robotics and other control systems.

Overview

The Muscle Mouse combines commercial-off-the-shelf (COTS) components, a printed circuit board (PCB), and a 3D printed enclosure to produce a low-cost and easy-to-build device. Having only one large button, the simplistic design of the Muscle Mouse makes it an ideal tool for the physically injured or disabled to strengthen targeted muscle groups, relearn actions through muscle memory, or participate in quantitative physical assessment tests all the while under the guise of simply having fun playing video games.

Muscle Mouse Design



- *Hardware*

The Muscle Mouse is powered by two 3xAAA battery packs configured to supply the PCB with a dual voltage supply (+-4.5V). A simple push button switch controls the flow of power from the batteries to the rest of the board. The brain of the Muscle Mouse is the powerful Arduino Pro Mini (3.3V version) which monitors the muscle sensor and controls the Bluetooth module. Connected to this Arduino's analog input port is an Advancer Technologies's Muscle Sensor v3 sensor.

Figure 1. Arduino Pro Mini

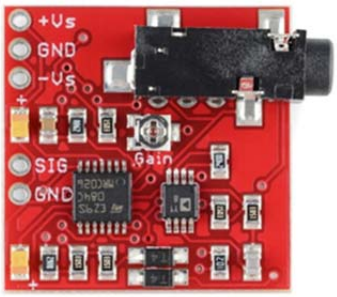


Figure 2. Advancer Technologies Muscle Sensor v3

This first of its kind sensor is a small, low-cost, and easy to use EMG circuit. The sensor comes with a cable that connects the 3.5mm port of the board to the electrodes placed on the user's targeted muscle. When the user flexes their muscle, the sensor amplifies the voltage difference between the two electrodes on the muscle, filters the signal, then transforms the signal completely into the positive voltage domain using a full wave rectifier, and lastly smoothes the rectified signal. This signal conditioning is especially designed for microcontrollers such as the Arduino series.

The Arduino Pro Mini is also connected to a SparkFun Electronics's BluSMiRF HID Bluetooth module breakout board. A Roving Network RN-42 HID Bluetooth module using its HID Mouse configuration is the heart of this board. This module handles all the Bluetooth protocols of the Muscle Mouse like pairing with and transmitting commands to a Bluetooth capable device (like a computer, tablet, or smart phone). Using standard HID mouse protocols, the Arduino can simply send button press or button release commands to the BluSMiRF, the BluSMiRF will transmit the commands, and the paired device will perform the transmitted command.

Figure 3. BluSMiRF HID Bluetooth Module

Additionally, the Muscle Mouse has three LED light indicators: one blue, one red, and one green. The red and green LEDs are on the BluSMiRF module and they indicate its status. When the Muscle Mouse is first turned on, the BluSMiRF will blink the red LED on and off to indicate it is waiting to be paired to a Bluetooth device. When the module is connected, the red LED turns of and the green LED turns on and remains on while the device remains connected. The blue LED is used to indicate when the Arduino senses muscle flexion. When the user flexes their muscle and the Muscle Sensor's output voltage increases above the hardcoded threshold value, the Arduino will turn the blue LED on. When the muscle relaxes and the sensor's output voltage decreases below the threshold value, the Arduino will turn the blue LED off.

Muscle Mouse's custom PCB was designed using CadSoft's EAGLE PCB design software. Each component's physical dimensions and pin layouts were modeled in the EAGLE software. The components were first connected along with the LED and power circuitry using the EAGLE schematic utility. Next the physical components were positioned using EAGLEs board design tool and the electrical traces were laid out using the EAGLE autotrace tool. Gerber files were then created using the CAM tool and then sent off to OSH Park (a PCB manufacturing house) to be printed.

```
void setup()
{
  pinMode(ledPin, OUTPUT);
  pinMode(sensorPin, INPUT);

  Serial.begin(115200);
  delay(100);
}

void loop()
{
  UpdateState();
  SendSerial();
}
```

- *Software*

The Muscle Mouse is programed using Arduino's open-source programming environment. This language is very similar to C++ and other popular languages. A typical program using this environment consists of a setup() and a loop() function. The setup() function is used to setup and initialize variables, pin configurations, and serial communications.

```
void UpdateState()
{
  //SENSOR - RIGHT
   int val = analogRead(sensorPin);
  if(val >= iThreshold)
  {
    bPrevSensorState = bCurrSensorState;
    bCurrSensorState = true;
  }
  else
  {
    bPrevSensorState = bCurrSensorState;
    bCurrSensorState = false;
  }

  delay(10);
}
```

The Muscle Mouse programing uses the setup() function to configure the digital output pin of the blue LED (pin 10), the analog input pin for the muscle sensor (pin A0), and to start the serial communication at the speed required for the BluSMiRF module (115200).

The code in the loop() function is what the Arduino will loop over repeatedly until it is powered down. The loop() function for the Muscle Mouse contains two function calls: UpdateState() and SendSerial().

The UpdateState() function reads the value of the Muscle sensor each loop cycle. The function then compares the sensor value to the preset threshold value (100). If the sensor value is over the threshold value, the function sets the current state of the sensor to true and stores the previous state of the

sensor. If the sensor value is not above the threshold value, the function sets the currents state of the sensor to false and stores the previous state. The function ends with a 10 millisecond delay to keep the programing from oversaturating the Arduino analog input pin by reading it too quickly.

```
void SendSerial()
{
  byte press[7] =
  {0xFD,0x05,0x02,0x01,0x00,0x00,0x00};
  byte release[7] =
  {0xFD,0x05,0x02,0x00,0x00,0x00,0x00};

   if(bCurrSensorState &&
     !bPrevSensorState)
   {
      digitalWrite(ledPin, HIGH);
     Serial.write(press, 7);
  }
  else if(!bCurrSensorState &&
          bPrevSensorState)
  {
     digitalWrite(ledPin, LOW);
     Serial.write(release, 7);
  }
}
```

The SendSerial() function determines whether to send a command to the Bluetooth module to press or release the mouse button based on the sensor's current and previous state. These states are determined in the previously discussed UpdateState() function. If the current state is true and the previous state is false, this means the user recently flexed their muscle and the function sends the command to press the mouse button. If the current state is false and the previous state is true, this means the user recently relaxed their muscle and the function sends the command to release the mouse button.

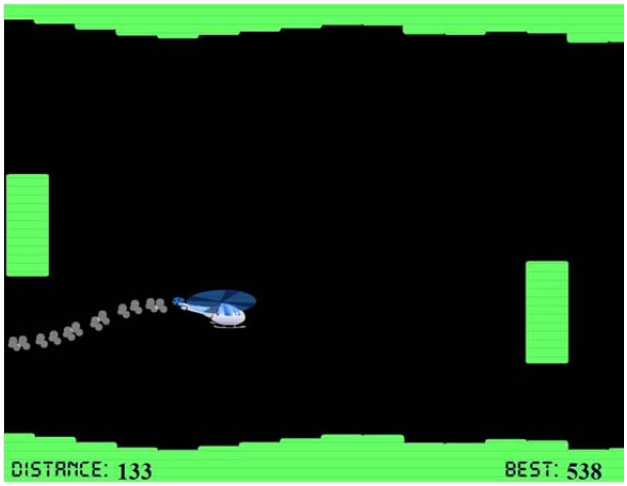
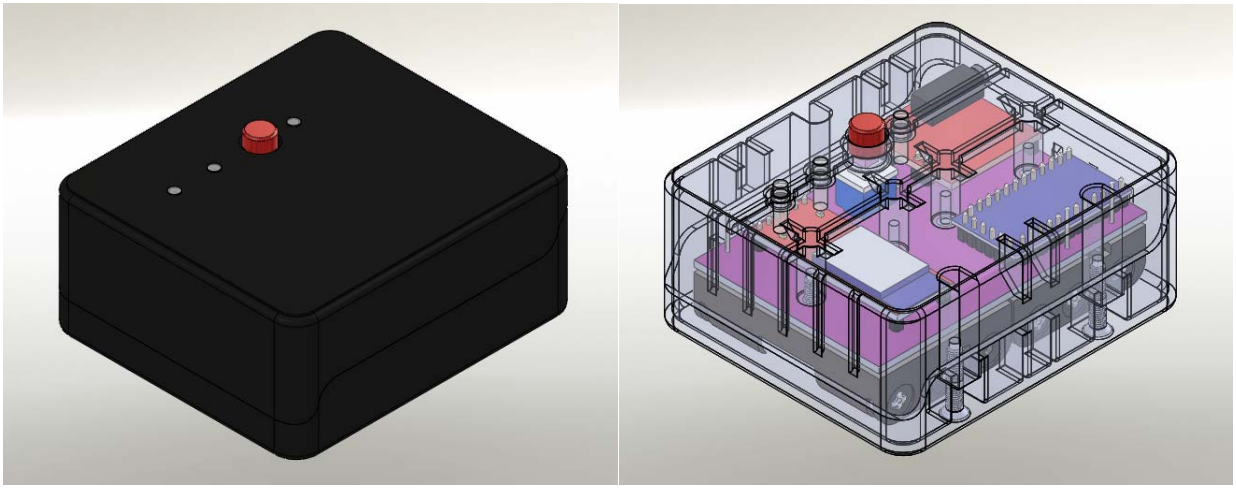


Figure 4. Classic helicopter game available for free on the internet.

The Muscle Mouse is designed to use these simple programs to allow the user play the classic helicopter game (shown below) on any mouse compatible Bluetooth device. The user simply has to navigate to any of the many available websites that provide this game for free and position the mouse cursor over the game window. The Muscle Mouse program gives the user the ability to navigate the helicopter through the game course by flexing their muscle to move the helicopter up and relaxing the muscle to move the helicopter down.

- *Enclosure*



Muscle Mouse enclosure was designed using Solidworks CAD software. The enclosure consists of two rectangular pieces. The top piece has holes designed for light pipes to be inserted. These light pipes ensure the light from the LEDs on the BluSMiRF's LEDs and the muscle indicator LED can be clearly seen. A fourth larger hole on the top of the enclosure exposes the push button ON/OFF switch and its button cap. The top piece has four board stand-offs with screw holes for the PCB board to be secured with 2.5M flat head screw. Additionally, there are three extrusions with 2.5M screw holes that slide into their complements on the bottom piece. The bottom piece has three through holes for 2.5M screws to be inserted. These screws when tightened are flush with the bottom of the piece.

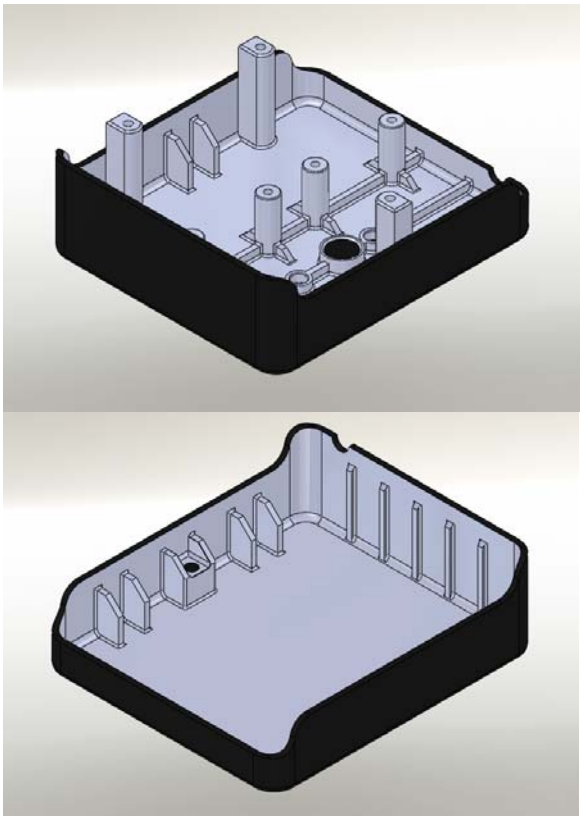


Figure 5. Muscle Mouse Solidworks Designed Enclosure Top (top) and Bottom (bottom)

The pieces were then exported as STL files and 3D printed using Selective Laser Sintering (SLS). After printing, the parts were sanded to 800 grit, primed with three coats Bondo Easy Finish Primer (sandable primer), and sanded to 800 grit. The pieces were finished with three coats of flat black Krylon Fusion For Plastic spray paint.

Applications

- *Occupational/Physical Therapy*

  Clinical studies have shown that patients recover more quickly if they are actively engaged and enthusiastic about rehabilitation. In recent years, physical and occupational therapists have sought to capitalize on this by integrating Nintendo's Wii Fit and Balance board into their therapy sessions. However, the Wii Fit is limited to primarily exercising the patient's core muscles and lower body. The Muscle Mouse will allow therapists to exercise any muscle group though irresistibly fun video games. Currently, the Muscle Mouse can be used to play a single free to play game but a more extensive line up of games specially designed to exercise target muscle groups could be implemented with minimal cost and effort. The low-cost technology behind the Muscle Mouse will be the first stepping stone into a whole new form of therapy that is both fun and meaningful.

- *Disabled Gaming / Wounded Warriors*

  With the ever-increasing assimilation of video games into society and everyday activities, victims of neuromuscular disease and injuries (e.g. stroke, ALS, MS, spinal cord injury, amputation, TBI, etc) grow frustratingly more disconnected from their former lives and the activities of their peers. To bridge this disconnect, a growing market has emerged providing specifically tailored game devices for disabled gamers. These devices allow disabled games to reengage in gaming despite their impairments but are very expensive (over $1,000). The Muscle Mouse technology will allow disabled gamers to reengage in video games while costing an order of magnitude less than currently available devices thanks to its use of COTS technology. Another key feature of the Muscle Mouse is its ability to allow a disabled person to use any muscle they have (with even the slightest of control) to play video games. Current devices are usually simply customized traditional controllers with larger buttons or switches. However, the Muscle Mouse uses electromyography to control games which means it is more adaptable to a wider range of disabilities. If a user has

voluntary control of even just one muscle, they will be able to use the Muscle Mouse to control games with less effort and more comfort than traditional controllers.

Future Work

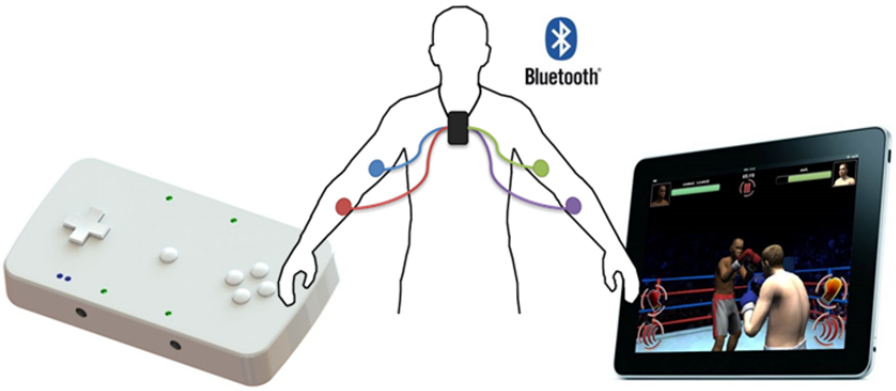


Figure 6. Surface Electromyography-based Network Accessible Patient Game System (SENAPS)

Advancer Technologies and Applied Research Associates (ARA) Virtual Heroes division are working together to further develop the Muscle Mouse into a muscle sensor video game controller for tablets and smart phones. This system, code named SENAPS, consists of a first-of-its-kind muscle sensor game controller and an irresistibly fun boxing game powered by the ever-popular Epic Unreal Engine.

The SENAPS controller is a small device worn loosely around the neck. The device has four cables with a set of electrodes snapped to each that are placed on up to four targeted muscle groups such as the forearms and biceps of both arms. The device automatically connects to tablets and smart phones by a Bluetooth connection. The SENAPS device has a fast, one step calibration process that allows the device to be uniquely tuned to each patient.

The SENAPS boxing game will be similar to the classic Nintendo® boxing game, *Punch-Out!!*™. The plot of the game will be for a player to advance through a series of boxing matches to eventually emerge as the champion. The game is intended to be played by using the forearms and biceps (to mimic boxing motions) but any four muscle groups can be used as well. To play the game, the patient will simply activate their left forearm to punch left, their right forearm to punch right, their left bicep to dodge left and their right bicep to dodge right.

Figure 7. SENAPS boxing game using Unreal Engine

About the Author

Brian Kaminski graduated in May, 2006 from North Carolina State University with a Bachelor's degree in Biomedical Engineering with a concentration in Biomechanics. While at North Carolina State University, Brian was involved in projects relating to biomechanics, biomaterials, tissue engineering, biomodeling, and biorobotics. Brian further pursued his engineering education at the University of Michigan - Ann Arbor from 2006 to 2007 where he received a Master's degree in Mechanical Engineering. Brian's graduate studies emphasized biomechanics, product design, and embedded hardware systems.

Brian currently works for the Southeast Division of Applied Research Associates (ARA) which he joined in 2008. Brian has worked on numerous biomedical efforts such as the HumanSim: Anethesia trainer, a head impact telemetry system for non-helmeted sports of his own creation, and a tactile feedback catheter trainer for Genentech. Brian is currently working with ARA's serious game development studio, Virtual Heroes, to develop a game-changing muscle sensor controlled video game system for disabled persons (victims neurological disease and stroke, wounded warriors, etc) to rengage in their favorite activity, playing video games.

In his spare time, Brian founded Advancer Technologies, a biomechatronic technologies company he founded to pursue his biomechatronic design and research projects. Advancer Technologies is a rapidly growing biomechatronic/biomedical company whose sensors can be found on electronic parts stores across the internet, such as SparkFun.com. Brian and his company are devoted to developing game-changing biomechatronic and biomedical technologies as well as cultivating and educating future generations of innovative scientific minds. To promote all forms of interest and learning into science and technology, Brian frequently posts informative tutorials and videos on how to incorporate biomedical technology into some amazing projects, such as a Myoelectric Video Game Controller and Bionic Iron Man Armor. Both of these tutorials' videos went viral on YouTube receiving over 363,000 views, collectively.

Appendix

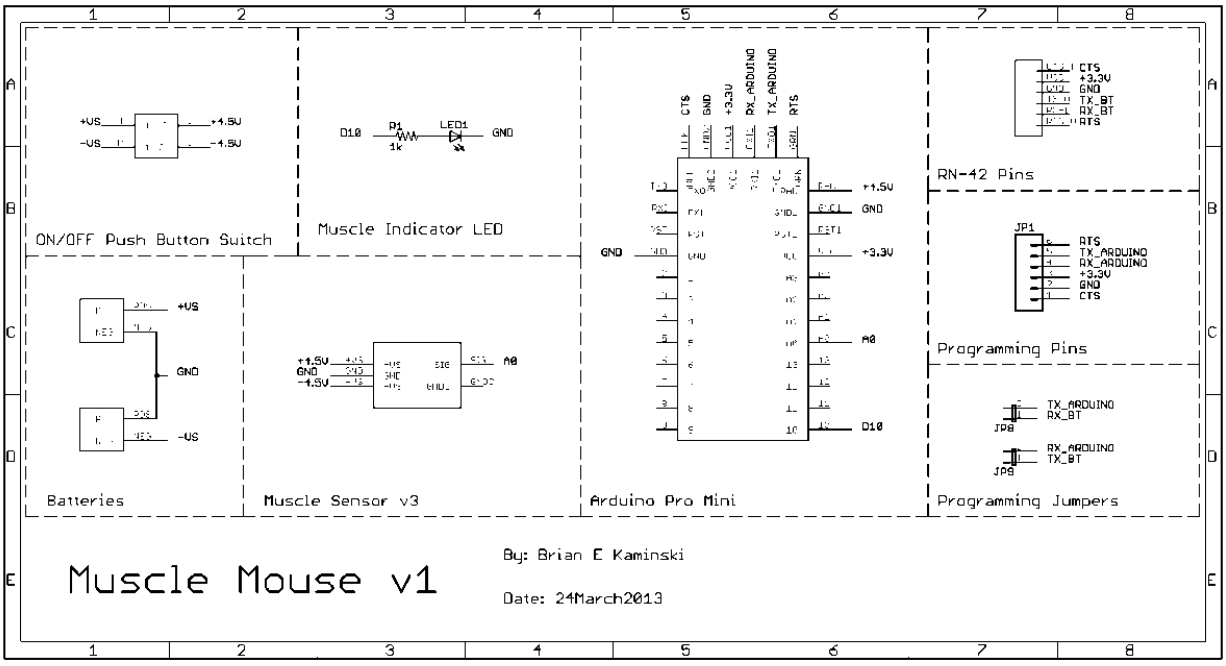


Figure 8. Muscle Mouse PCB Schematic

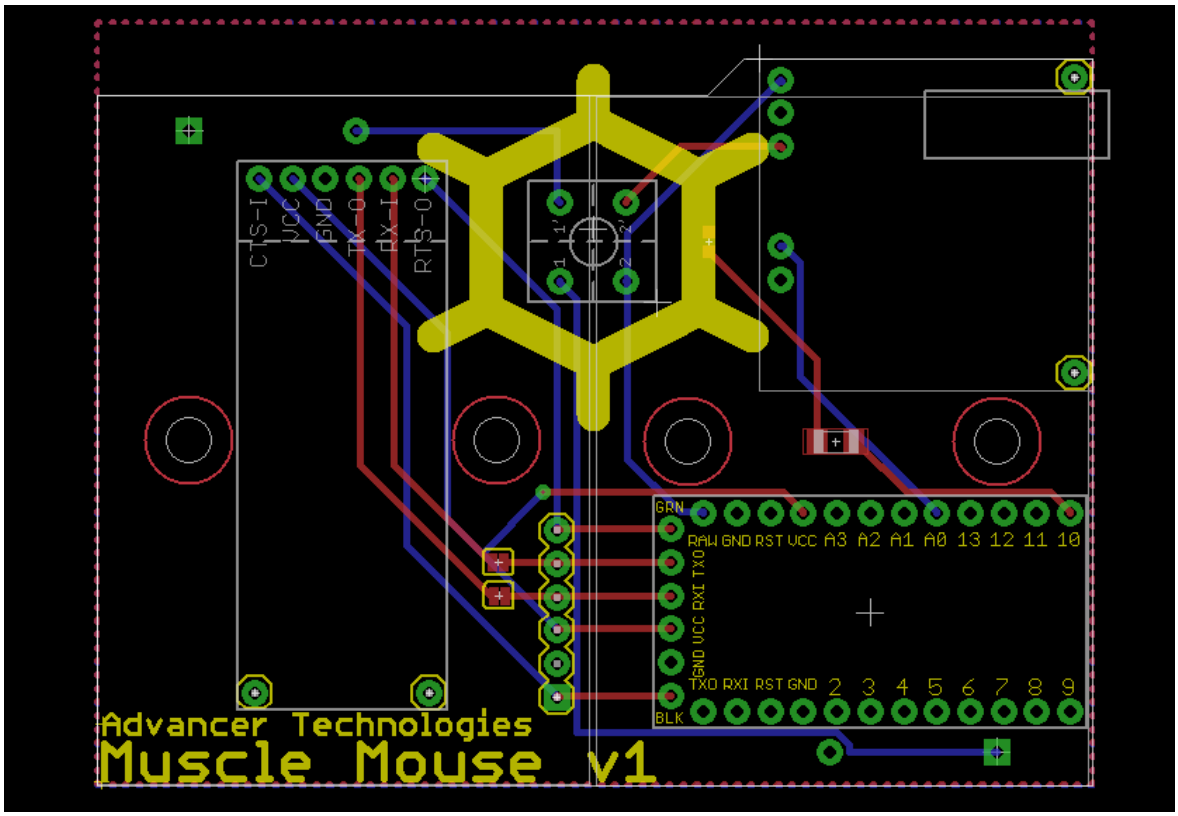


Figure 9. Muscle Mouse PCB Board Design

Setup Instructions

1. Place the electrodes on the targeted muscle group.
    - The first electrode should be placed on an inactive section of the body, such as the bony portion of the elbow, shin or forearm. This electrode is the reference or ground electrode and should be connected to the black cable.
    - The remaining two electrodes should be placed along the muscle selected to be measured. The second electrode should be placed along the mid length of the muscle; this electrode should be connected to the red cable. The last electrode should be placed at the end of the muscle and connected to the blue cable.
2. Plug the electrode cable into the Muscle Mouse port and turn on the device.
3. Connect the Muscle Mouse to the Bluetooth Device
    - Each time you use the Muscle Mouse with a new Bluetooth device, you'll need to pair the Muscle Mouse with the device. Follow your device's instructions on how to pair Bluetooth devices.
    - When the Muscle Mouse pairs/connects with the device, the blinking red light will turn off and a green light will turn on.
4. Navigate to the video game site such as http://www.helicopterplay.com/helicopter/thehelicoptergame.php
5. Move the cursor over the game window and play!

Cost Breakdown

Description	Vendor	Quantity	Unit Price	Price
Muscle Sensor v3 Kit	Advancer Technologies	1	$49.95	$49.95
Pro Mini	Arduino	1	$9.95	$9.95
BluSMiRF HID	Roving Networks	1	$44.95	$44.95
0.25" Light Pipe	Bivar Inc	3	$0.90	$2.70
Grey Button Cap	C&K Components	1	$0.34	$0.34
ON/OFF Push Button	C&K Components	1	$1.27	$1.27
AAA Battery Holder	Keystone Electronics	2	$1.84	$3.68
Blue LED	Rohm, Co	1	$0.60	$0.60
1k Ohm resistor	Vishay Dale	1	$0.09	$0.09
PCB Board	Custom	1	$10.88	$10.88
3D Printed Enclosure	Custom	1	$204.96	$204.96
2.5M Screw 10mm	McMaster-Carr	7	$0.06	$0.42
			TOTAL	**$329.79**

At large quantities the Muscle Mouse (>= 1000 units) ***would only cost around $80!***