# Single-Handed Video Game Controller

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# Contents

# 1 Introduction

## 1.1 Objective

Standard video games on the Xbox [1] and GameCube [2] are not accessible to people without the full use of two hands. Our group aims to design a one-hand video game console controller, which can be used by either hand. This device will preserve all common functionalities of a standard video game controller, but able to be manipulated with a single hand. Our controller will also be modular, so as to be extendable to different consoles and communication protocols. The product will primarily benefit players with physical disabilities in one of their hands or arms. This solution could also contribute to improvements in overall accessibility to games, and even in dexterity therapy regimens.

## 1.2 Visual Aid

Our project is a functional reorganization of a standard Xbox controller, which is shown in Figure 1. A noteworthy point is that we will be implementing a *wired* controller, and thus will not need to "pair" our device with the Xbox 360. Traditionally, the user's left thumb is responsible for the left stick and directional pad controls, while the domain of the user's right thumb is the face buttons X, Y, A, and B, as well as the right stick. We will take advantage of this observation in the design of our adaptive controller.

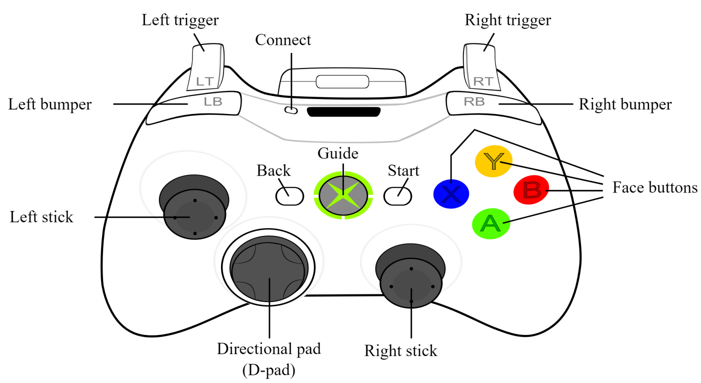



Figure 1: Buttons of a standard Xbox 360 controller [3]

## 1.3 Background

The video game "Call of Duty" requires players to do three things at the same time: move the player character, look around and shoot other players [4]. In order to accomplish this, players need to exhibit quick reaction times, and repetitive and simultaneous use of both hands. However, a family member of one member of our team only has use of one of their hands. Because of this, they cannot do everything that is required at the same time with a standard two-handed controller, making it impossible for the two to play together.

There are over 2 million Americans who have had limbs amputated or were born with limb abnormalities, many of whom lost some or all functionality in their arm or hand [5]. Additionally, a study by Information Solutions Group stated that 22% of gamers have some sort of disability, 46% of whom have primarily a physical disability. Gaming may not just pose a hindrance to people with disabilities, but also as a tool for therapy. Eleven percent of survey-takers reported that a medical professional recommended playing games as a treatment [6]. Our project is an option for players who have difficulty gripping and utilizing a two-handed controller, but may find the usage of a one-handed alternative more accessible.

Currently, potential gamers within our population of focus have few adequate options that function as a general adaptive solution. The most common mechanism on the market to address these obstacles would appear to be the gaming joystick. These controllers, however, generally fall into one of two categories: Overly complex, gigantic joysticks that need to be programmed, or overly simplistic joysticks that are limited to a certain few select games. Our project is unique because it is plug-and-play, meaning it does not need to be programmed. Additionally, because it is designed to be general-use and fully operational, the controller can play any game that a regular controller could, because all of the original controller's functionality is preserved.

## 1.4 High-Level Requirement List

Our project needs to meet several criteria in order to address our problem adequately. These requirements ensure our design's purpose is fulfilled, the product functions fully, and it is usable for our intended target customers.

- The product must map all controls commonly performed on a two-handed controller, so that it all can be done with a single hand.
- The controller should communicate with at least one type of standard video game console (Xbox 360), with a flexible modular design to facilitate connections to various consoles.
- The adaptive controller will be usable regardless of using only your left or right hand.

# 2 Design

When designing a video game controller, we need to take into account several functionalities that are needed. Figure 2 shows the overview block diagram for our design, and table 1 shows some concept illustrations.

## 2.1 Functional Overview

Our project needs to combine the functionality of six fingers (three left and three right) into just three fingers and the wrist. We will accomplish this by compounding certain button groups, remaining mindful of common button combinations.

### 2.1.1 Sensors

Our project will be primarily sensor-based, because it is meant to be controlled and manipulated by the user. Digital sensors will include all of the buttons and the twisting mechanism, while analog values are needed for the directional controls and triggers.

- Touch sensors: The touch sensors will function as buttons on the controller. All the touch sensors must provide digital output signals in order to operate each button.
  - The bumper buttons will share the distinction of our trickiest implementation with the twist sensor mechanism. We will need to couple the trigger motion with an additional sideways click for the index and middle fingers.
- Joystick and Circle Pad: The joystick and circle pad will function as the left and right stick, respectively, as shown on the controller in Figure 1.
  - Each mechanism provides analog output signals on X and Y direction and digital output signal on Z direction. The main joystick will be attached to the control unit box as it is shown in the physical design picture, and the circle pad will be attached on the top of the main joystick.
  - Our joystick combines the functionality of the left and right sides of the controller by allowing the wrist to do everything that the left thumb would normally do. This means that, through the twist sensor, the user toggles what the joystick position means. All other major buttons are mapped to the handle of the joystick.
- Triggers: The user needs to generate an analog output signal when each trigger button is pressed. These signals will be used for L2 and R2 buttons in our controller. Our input module of the control unit will interpret this reading as a discrete integer from 0-255 and send it to the console. While a traditional controller uses a magnet and proximity sensor to implement the trigger mechanism, we plan to take a simpler approach, applying a rotational potentiometer to accomplish this goal.
- Twist Sensors: The twist sensor will change the functionality of the main joystick from the circle pad to the direction pad. If we inspect normal controller usage during game-play, the left stick and left directional pad controller are very rarely used simultaneously. The usage of the twisting degree of freedom allows for the combination of two mostly disjoint operations, without committing this switch to a finger. The twist sensor, when engaged, will cause the joystick orientation to be interpreted as the directional The twist sensor will be one of our two most challenging components from a mechanical perspective.

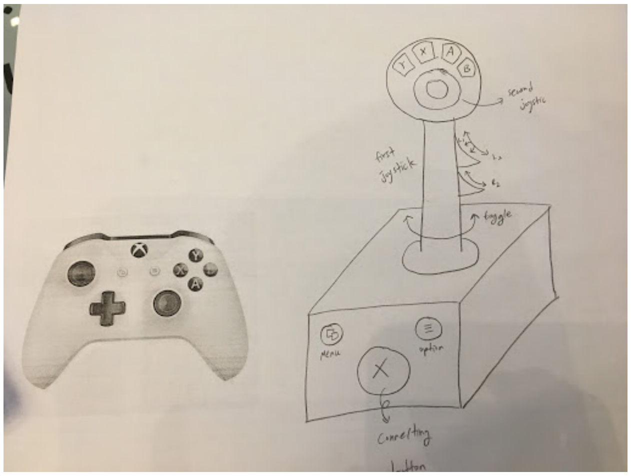
### 2.1.2 Control Unit

The control unit will be divided into two sub-modules: the input unit and the communication unit. A microcontroller will be used for each part of the control unit for the one-handed controller, to both provide enough computing power, and keep the price of the controller relatively low. The sensors are connected to the input chip through wires. The microcontroller is programmed so that each sensor is mapped to hold the function of one button or joystick of an original Xbox 360. When the user provides input information through the sensors by interacting with buttons and joy-sticks, the input unit will relate the signal from the sensors accordingly to Xbox controller buttons, and instruct the communication unit to send the information to the console the user is playing on, such as the Xbox 360 [7] and Nintendo GameCube [8], taking inspiration from protocols and libraries we have gathered from the internet.

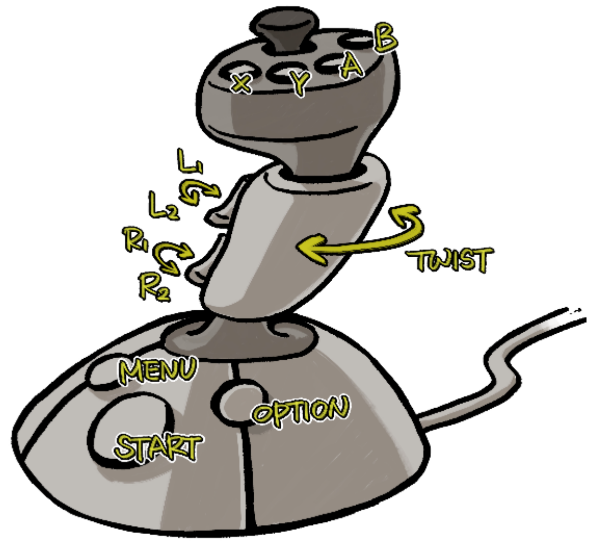
### 2.1.3 Power Supply & Connection with Console

- A power supply is required for the controller to function. The controller will be powered through a USB cable connected to the console, which provides electricity for the electronic parts and microcontroller to function. This also allows the controller and specifically the communication unit to have I/O communications with the console.

Table 1: Design illustrations.



(a) Initial concept sketch.




(b) Digital mockup of controller design

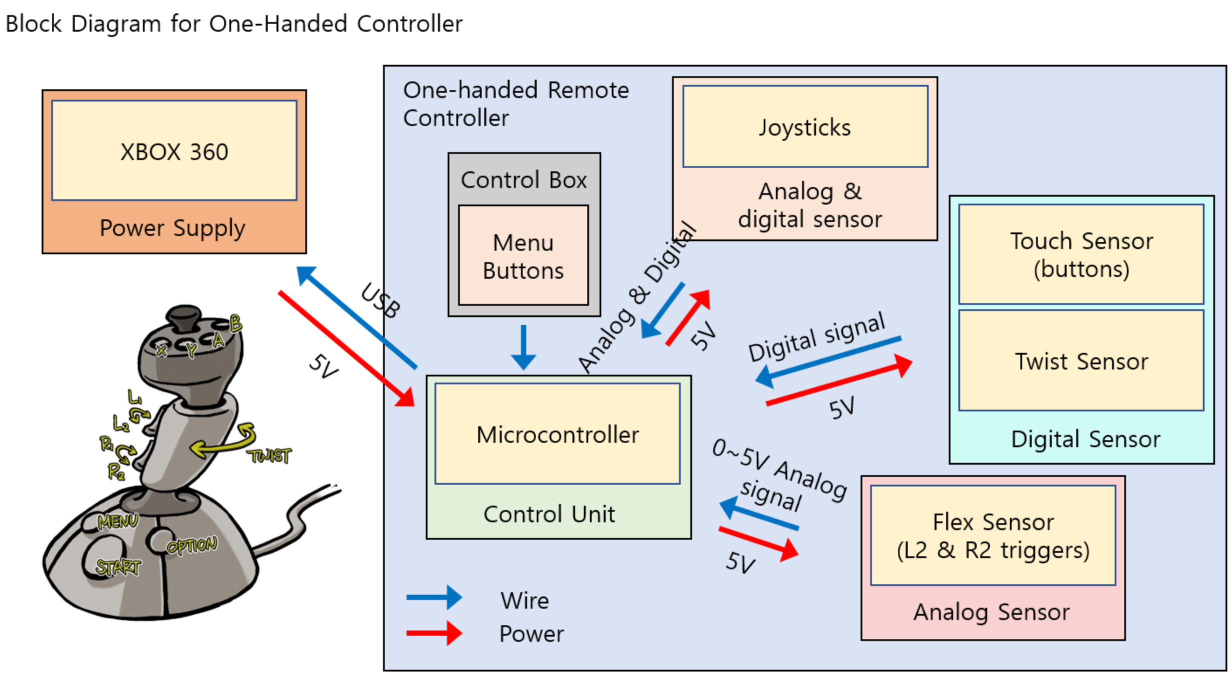



Figure 2: Block diagram for one-handed video game controller.

## 2.2 Block Requirements

This section describes the functionality requirements of each major component within the controller.

### 2.2.1 Computational Unit

This component must take in the values of all buttons, triggers, and stick controls, as well as control the communication unit. The ATmega328P chip should provide the functionality we need for this Table 2 shows the requirements for this module.

Table 2: Requirements and verification for the control unit.

| Requirement | Verification | Points | Verified? |
|---|---|---|---|
| The microcontroller must accept and monitor 18 sensor inputs concurrently:<br>1. Analog Inputs (6)<br>(a) 2x2 analog circle pad reading<br>(b) 2x analog trigger reading<br>2. Digital Inputs (12)<br>(a) 4x X,Y,A,B buttons<br>(b) 2x joystick push buttons<br>(c) 2x R2, L2 bumpers<br>(d) 1x Left stick / Left D-pad toggle (twist sensor)<br>(e) Start button<br>(f) Back button<br>(g) Reset button | We will demonstrate a computer program responding to the user pressing each button on the controller. | 7.5 | . |

### 2.2.2 Communication Unit

A separate processor will be needed to implement communications between the console and the controller. This communication will rely on An ATmega16U2 chip should be able handle to the USB communications as directed by the input unit.

Table 3: Requirements and verification for the control unit.

| Requirement | Verification | Points | Verified? |
|---|---|---|---|
| Organize digital and analog readings into controller protocol array and send to console at least 20 Hz (via USB) | We will demonstrate a computer program measuring the rate of information exchange. | 7.5 | . |

### 2.2.3 Digital Sensors

The digital inputs for our project will consist of the standard buttons, the twist sensor, and the bumper buttons, and the pressing of the stick controls. The buttons will map directly to their counterparts on the

Xbox controller. They will be arranged on the side of the controller handle, near the top for easy access by the thumb. The on the head of the joystick, the buttons will be organized similarly to a traditional controller. The twist sensor will toggle between the functionality of the directional pad and the left stick, depending on whether the handle of the controller is twisted by about 30-45°. The bumpers will be augmented onto the trigger buttons, in order to combine multiple gestures into individual fingers. Table 4 shows the requirements for this module.

Table 4: Requirements and verification for the buttons.

| Requirement | Verification | Points | Verified? |
|---|---|---|---|
| The digital inputs must provide a digital signal with digital 1 between 1-5 V corresponding to when the sensor is engaged / pressed. | We will demonstrate a computer program responding to the user pressing each button on the controller. | 5 | . |
| The twisting mechanism must be sprung towards default position. | We will demonstrate someone rotating the joystick and observing it homing back to the default position. | 5 | . |

### 2.2.4 One-Dimensional Analog Sensors

The triggers will function similarly to those on the traditional controller, but with a different implementation. Table 5 shows the requirements for this module.

Table 5: Requirements and verification for the Triggers.

| Requirement | Verification | Points | Verified? |
|---|---|---|---|
| The triggers must provide analog reading for the amount of trigger depression between 0-5 V | We will demonstrate a computer program responding to the user pressing each trigger on the controller. | 5 | . |
| The triggers' range of motion must be restricted to in/out | We will demonstrate someone pressing each trigger and observing the motion of the trigger mechanism. | 5 | . |
| The triggers must be sprung out. | We will demonstrate someone pressing each trigger and observing it return to the default position. | 5 | . |

### 2.2.5 Two-Dimensional Analog Sensors

The circle pads directly map functionally from the traditional controller. The "right" stick will be placed the head of the controller, while joystick itself will implement the "left" stick. Table 6 shows the requirements for this module.

Table 6: Requirements and verification for the circle pads.

| Requirement | Verification | Points | Verified? |
|---|---|---|---|
| Must provide 2D analog reading of X/Y orientation, between 0-5 V | We will demonstrate a computer program responding to the user pressing each button on the controller. | 5 | . |
| Must provide digital push reading with digital 1 between 1-5 V (press the stick in) | We will demonstrate a computer program responding to the user pressing each button on the controller. | 5 | . |

## 2.3 Schematics

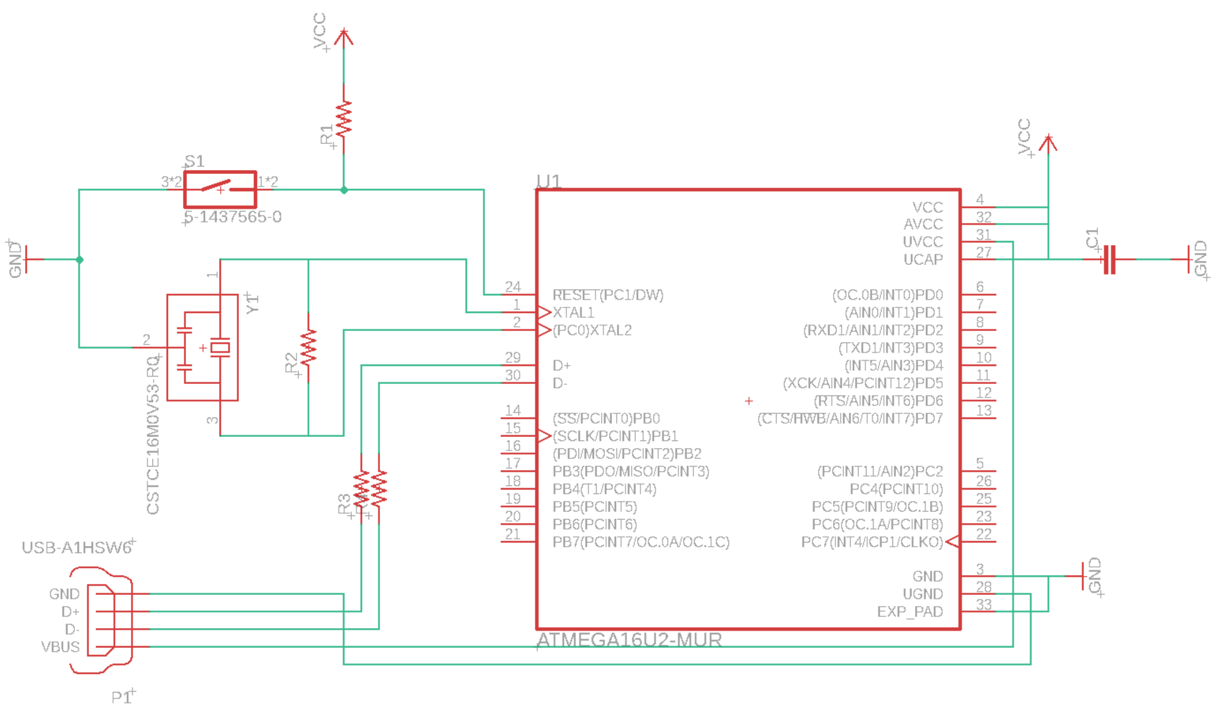



Figure 3: USB Schematic (ATMEGA16U2)

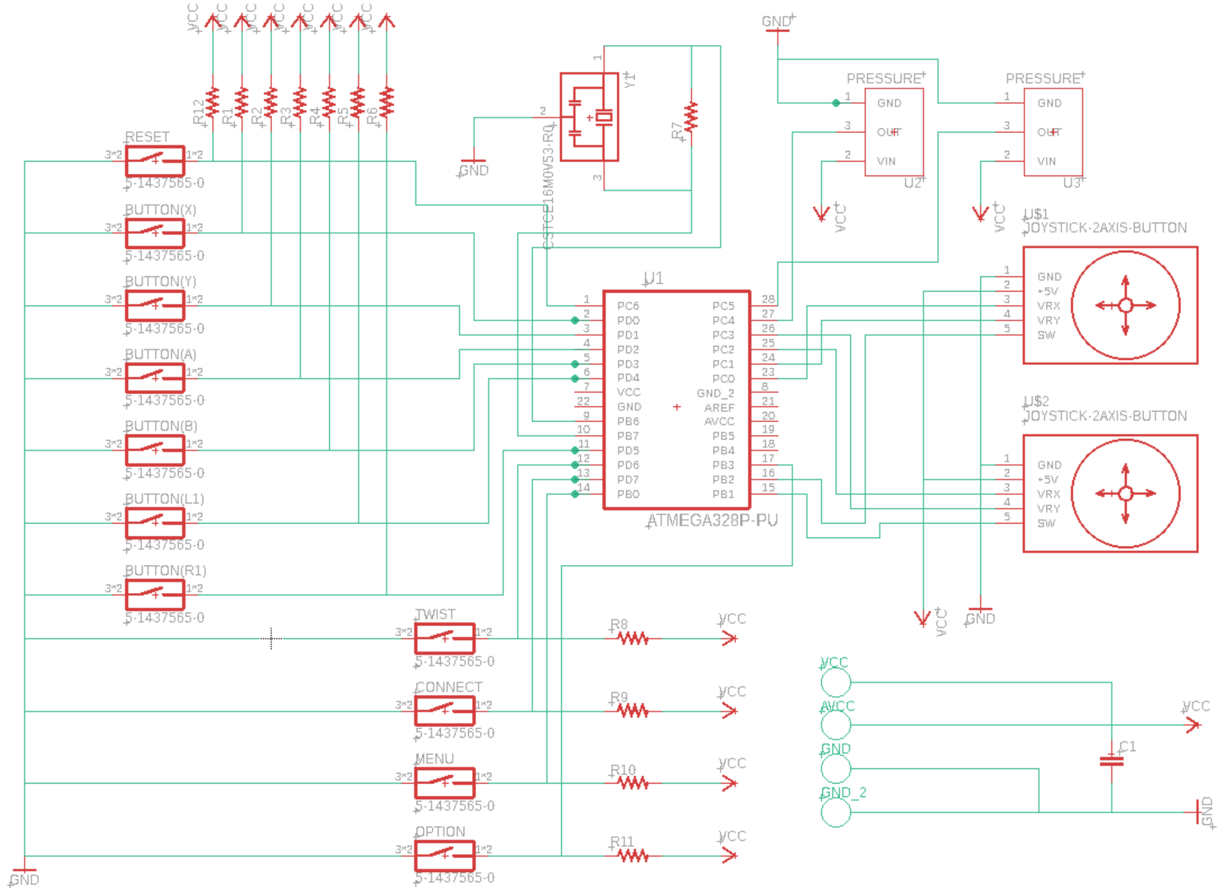
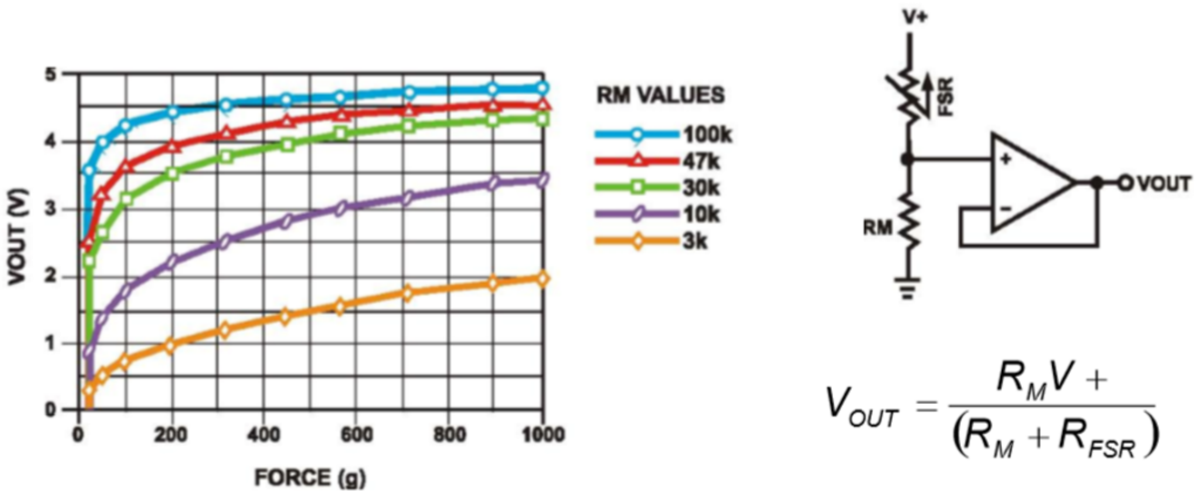



Figure 4: Sensors Schematic (ATMEGA328P)

## 2.4 Plots and Calculation

1. We are alternatively considering using a thin-film pressure sensor, which is a two-wire device with a resistance that depends on the applied force. In order to measure the magnitude of the applied force, a simple force-to-voltage conversion needs to be calculated so that the sensor can provide analog signal output through this $V_{out}$. The formula for this calculation and the relationship between the force and resistance are shown in Figure 5.




$$V_{OUT} = \frac{R_M V+}{(R_M + R_{FSR})}$$

Figure 5: Plot & Calculation for Pressure Sensor

## 2.5 Algorithm Overview

Our project will not be computationally heavy, but the microcontroller will need to perform several basic functions to facilitate the functionalities of the adaptive controller. Figure 6 shows the responsibilities of the input and communication processor components.

The input component will be solely responsible for polling the many buttons and analog sensors in our controller. These readings will be stored for whenever the communication unit needs them. Our controller will be primarily overseen by the communication unit, which will ask the input unit for readings to send to the console at a rate of **at least 20 Hz**.

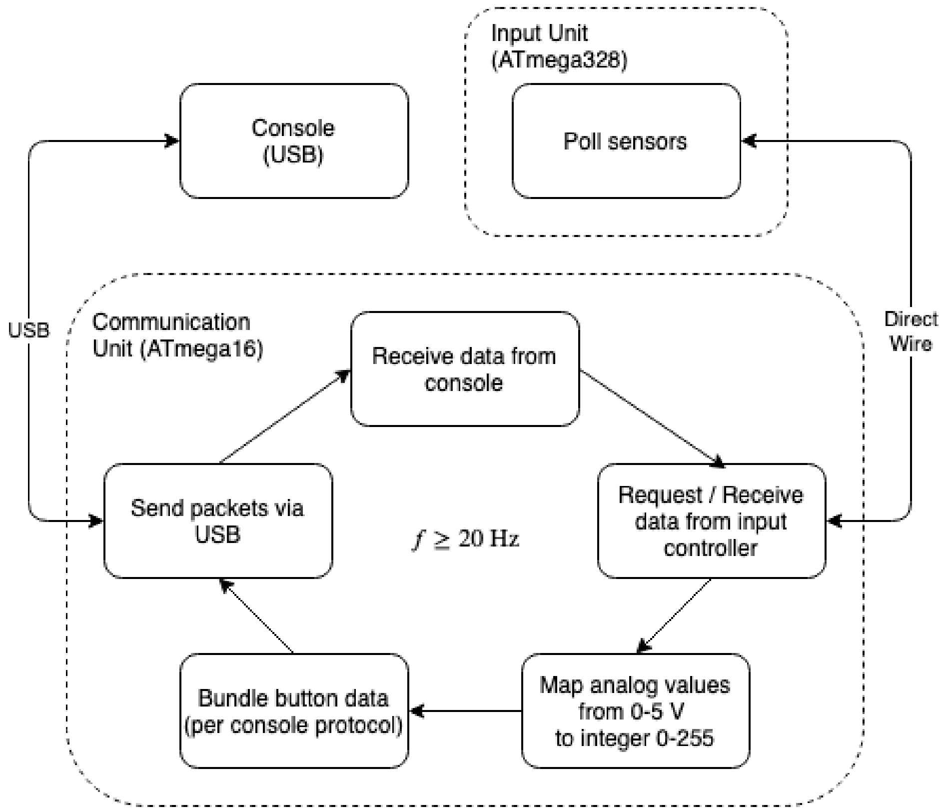



Figure 6: Basic algorithm for the controller chips.

## 2.6 Tolerance Analysis

Several of our modules will need to conform to a set of minimum performance standards in order for our product to be useful. The two components that will pose the biggest challenges will be the twisting mechanism on the joystick and the implementation of the triggers and bumpers. We will need to figure out how we will mount the twisting part, and how we will sense the twisting. The machine shop will be a resource for us with this mechanism. Furthermore, we must ensure that the range of twisting is limited.

For the triggers and bumpers, we need to implement two degrees of freedom, one serving an analog functionality and the other responding digitally. In both cases, the mechanisms need to be sprung, and thoroughly tested to ensure usability. While both mechanisms will be challenging mechanically, we will focus on the trigger sensors due to the need for an analog signal.

We plan to use a potentiometer for the trigger sensing, instead of using a flex sensor as originally planned, due to its spacial complications. The potentiometer will change its resistance based on the angle of the trigger, Using an angle spring, we will cause the trigger to default to being pressed out. Figure 7 shows how we can use the rotational position of the trigger to deliver a variable signal to the microcontroller.

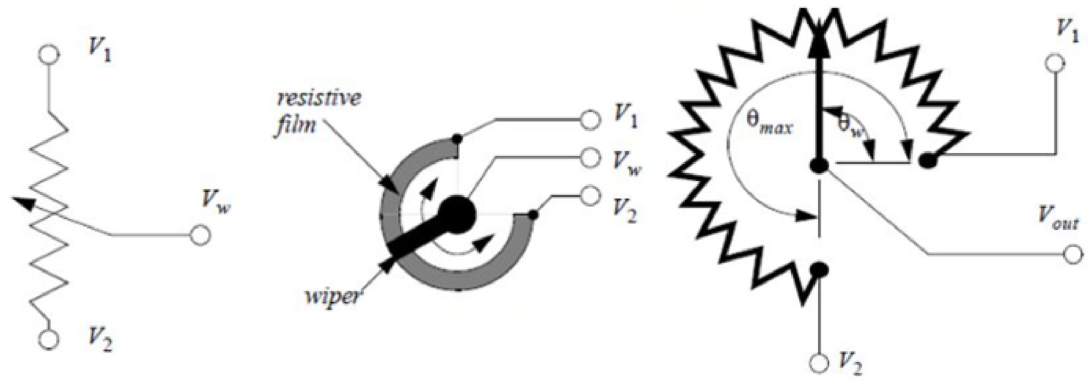



Figure 7: Graphical representations of the potentiometer [9]

The microcontroller will need to be able to distinguish a minimum granularity of output voltages from the potentiometer. The equation for the voltage from the potentiometer is given in equation 1.

$$V_{out} = (V_2 - V_1)\left(\frac{\theta_W}{\theta_{max}}\right) + V_1 \quad (1)$$

In order to satisfy the purposes of an analog trigger, the microcontroller must be able to distinguish at least **3 (three) unique voltages** from the trigger sensor. As explained in the algorithm overview, we will attempt to map the range of voltages from 0-5 V to an integer, which will be sent to the console. This will easily be a feasible implementation, as we will be mapping the analog reading to an 8-bit integer. We will thus easily be able to distinguish at least three separate values.

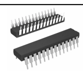
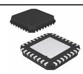
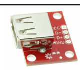
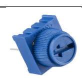
A few other points of additional tolerance information include:

1. The twist sensor needs to change the function of the joystick successfully, and go back to original position after twisting with a use of spring.
2. Resistors range from 100 Ω - 10 kΩ, and Capacitors range from 10 nF to 100 µF are needed to keep the circuit stable.

# 3 Cost Analysis

Specific parts, price, and links are listed below.

## 3.1 Bill of Materials

| Part/Link | Mft | Desc | Price | Qty | Total |
|---|---|---|---|---|---|
| CSTCE16M0V53-R0  | Murata Electronics | CERAMIC RES 16.0000MHZ 15PF SMD | $0.50 | 2 | $1.00 |
| ATMEGA328P-PU  | Microchip Technology | IC MCU 8BIT 32KB FLASH 28DIP | $2.08 | 1 | $2.08 |
| ATMEGA16U2-MUR  | Microchip Technology | IC MCU 8BIT 16KB FLASH 32VQFN | $2.52 | 1 | $2.52 |
| WMYCONGCONG  | WGCD | 37x25x32mm 15g +5Vcc | $12.99 | 1 | $12.9 |
| BOB-12700  | SparkFun Electronics | SPARKFUN USB TYPE A FEMALE BREAK | $4.50 | 1 | $4.50 |
| COM-09806  | Sparkfun Electronics | TRIMMER 10K OHM 0.5W PC PIN TOP | $0.95 | 2 | $1.9 |
| Push buttons (from ECE electronic shop) | UIUC ECE | 5V, Digital | 0 | 10 | 0 |
| Resistors (from ECE electronic shop) | UIUC ECE | 100 - 10k Ohm | 0 | 5-20 | 0 |
| Capacitors from ECE electronic shop | UIUC ECE | 10n - 100u F | 0 | 5-20 | 0 |
| Total Price | | | | | $24.90 |

## 3.2 Cost of Labor

The estimated working time per week for our group is 6 - 9 hours, with 8 hours weekly average through the semester. Two meetings of 3 hours are made on average presently, but an increase to 3 meeting total 9 hours is expected as the actual parts come in. Each of our group member is paid with $25 / hr, which is a typical engineer salary. Factoring in Hofstadter's Law [10], we would expect the cost of labor to be

$$2.5 * 16 * 8 \text{ hrs} * \$25/\text{hr} * 3 = \$24000.$$

## 3.3 Total Cost

The total cost would be $24.90 + $24000 = $24024.90.

## 4 Schedule

| Week | Tasks | Members |
|---|---|---|
| 02/17 | Design Document - Blcok Requirement;<br>Research chip to use; | Marshall |
| | Design Document - Block Diagrams;<br>Design Document - Schematic;<br>Research sensors to buy; | Seongje |
| | Design Document - Cost Analysis;<br>Research USB module. | Yaning |
| 02/24 | Design document check;<br>Design Document - Tolerance Analysis;<br>Design Document - Formatting; | Marshall |
| | Design document check;<br>Design Document - Block Diagram Improve; | Seongje |
| | Design document check;<br>Design Document - Schedule; | Yaning |
| 03/02 | Design document review;<br>Discuss parts needed fro machine shopt<br>Conversation with machine shop;<br>Design PCB;<br>Discuss PCB order with TA;<br>Possibly pass PCBway's audit. | Marshall |
| | Design document review;<br>Discuss parts needed fro machine shopt<br>Design PCB;<br>Discuss PCB order with TA;<br>Possibly pass PCBway's audit. | Seongje |
| | Design document review;<br>Discuss parts needed fro machine shopt<br>Design PCB;<br>Discuss PCB order with TA;<br>Possibly pass PCBway's audit. | Yaning |
| 03/09 | Teamwork evaluation 1;<br>PCB design improve;<br>Possibly pass PCBway's audit;<br>Early bird PCBway order (5 bonus points);<br>Order necessary parts line;<br>Soldering assignment. | Marshall |

| | | |
|---|---|---|
| | Teamwork evaluation 1;<br>PCB design improve;<br>Possibly pass PCBway's audit;<br>Early bird PCBway order (5 bonus points);<br>Soldering assignment. | Soengje |
| | Teamwork evaluation 1;<br>PCB design improve;<br>Possibly pass PCBway's audit;<br>Early bird PCBway order (5 bonus points);<br>Soldering assignment. | Yaning |
| 03/16 | Test code on XBOX console;<br>Test chips and sensors. | Marshall |
| | Assemble parts;<br>Test code on XBOX console; | Seongje |
| | Assemble parts;<br>Test chips and sensors. | Yaning |
| 03/23 | MUST pass PCBway's audit;<br>First round PCBway order;<br>Last day for machine shop revision;<br>Individual progress reports due 03/30;<br>Test code on XBOX console;<br>Test chips and sensors. | Marshall |
| | MUST pass PCBway's audit;<br>First round PCBway order;<br>Last day for machine shop revision;<br>Individual progress reports due 03/30;<br>Assemble parts;<br>Test code on XBOX console; | Seongje |
| | MUST pass PCBway's audit;<br>First round PCBway order;<br>Last day for machine shop revision;<br>Individual progress reports due 03/30;<br>Assemble parts;<br>Test chips and sensors. | Yaning |
| 03/30 | Individual progress reports due Monday<br>Test code on XBOX console;<br>Test chips and sensors. | Marshall |
| | Individual progress reports due Monday<br>Assemble parts;<br>Test code on XBOX console; | Seongje |

| | | |
|---|---|---|
| | Individual progress reports due Monday<br>Assemble parts;<br>Test chips and sensors. | Yaning |
| 04/06 | Final Round PCBway Orders;<br>Prepare for Mock Demo | Marshall |
| | Prepare for Mock Demo | Seongje |
| | Prepare for Mock Demo | Yaning |
| 04/13 | Prepare for Mock Demo<br>Debugging | Marshall |
| | Prepare for Mock Demo<br>Testing on console | Seongje |
| | Prepare for Mock Demo<br>Testing on console | Yaning |
| 04/20 | MOCK DEMO;<br>Prepare for presentation | Group |
| 04/27 | DEMONSTRATION;<br>Prepare for presentation;<br>Final report<br>Write lab notebook | Group |
| 05/04 | PRESENTATION;<br>Finish final paper;<br>Lab notebook due;<br>Lab checkout;<br>Team evaluation 2 | Group |

# 5 Conclusion

We do not have any serious ethical concerns over this project, although we do need to concentrate on certain safety aspects [11].

## 5.1 Ethical considerations

- In observation of IEEE Policy 7.8.9, we want to refrain from physically damaging whatever video game consoles with which we interact, and so we will use the standard USB protocol to minimize the probability of miscommunication.
- Our controller shall not be able to enable malicious actions to be performed on the console, which otherwise would not be possible with a standard video game controller. Through this effort, we will also be fulfilling IEEE Policy 7.8.9.
- In the spirit of IEEE Policy 7.8.7 and 7.8.8, we will strive to test our design with the family member of our group mate. We value their feedback especially because they would be someone who should benefit from our project.
- We are creating a project which solves a unique set of problems, but our controller may appear similar to other more common joysticks. We must meet the criteria of our high-level requirements in order to ensure our project remains a unique solution as per IEEE Policy 7.8.7.

## 5.2 Safety

- Due to the quick, reaction-based nature of many video games, we need to expect considerable wear and stress on the controller. In compliance with IEEE Policy 7.8.1, we will seek to have all electronic components be secured within the controller body so as to avoid any electrical exposure.
- Our entire project is a human interface, and so we must ensure that the casing of the controller is safe for people to touch. We plan to 3D print our outer casing of the handle, and so these materials are generally safe for humans to touch and grip.
- Also with respect to IEEE Policy 7.8.1, the shell of the controller needs to be relatively strong, so kids and pets cannot break it open and accidentally swallow small parts.
- The device is not waterproofed, so it should not be exposed to wet environments. We will make this clear with a label in an effort to comply with IEEE Policy 7.8.9.

# References


[1] W. Contributors, “Xbox 360,” 01 2020. [Online]. Available: https://en.wikipedia.org/wiki/Xbox_360

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[11] IEEE, “Ieee code of ethics,” 2018. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html

# Appendix A Sensors We Have in Mind

This section provides a few links to sensors we are thinking of using in our project.

- Buttons: 6 x Tactile Button Module for Arduino, Raspberry Pi 6 Color set, Science Project `https://ebay.us/qbknZW`
- Trigger analog sensor: KEYESTUDIO 0-0.5kg Thin-film Pressure Force Sensor Module for Arduino Micro bit `https://ebay.us/gEpMVQ`
- Circle Pads: Analog 2-axis Thumb Joystick with Select Button + Breakout Board `https://www.adafruit.com/product/512?gclid=EAIaIQobChMIq_r0s6a55wIVSrzACh3swQozEAkYAyABEgKhrPD_BwE`
- Microcontroller: ATmega328P-PU `https://www.digikey.com/short/z3d2rr`
  - We will need USB as well for programming and communication protocol
  - Possibly V-USB `https://www.obdev.at/products/vusb/index.htmlorintermediatechip`