**System Requirements**

**Functional Requirements:**

1. The system shall implement a two-player pong-style video game (conceptually patterned after the Atari “Pong” video game).

2. The system shall project vector-based video game graphics onto a two-dimensional rectangular surface using a dynamically steered laser beam.

3. The system shall modulate the intensity of the beam to ensure individual graphical elements appear separated from one another (i.e., no unwanted “connecting” lines are visible).

4. The system shall display a graphical “paddle” for each player.

5. The system shall accept individual input from each player to control the vertical position of their respective paddle.

6. The system shall display a graphical “ping pong ball”.

7. The system shall animate the motion of the ball to simulate physical ping pong in a manner similar to the Atari “Pong” video game.

8. The system shall display a graphical boundary indicating solid edges of the playing area (i.e., boundaries that will cause the ball to bounce).

9. The system shall provide a control input to start/restart the game.

10. The system shall keep score for both players.

11. The player scores shall be graphically displayed.

12. The system shall end the game when a player first reaches a score of 10 goals.

13. The system shall provide an audio sound effect when the ball bounces off a boundary.

14. The system shall provide an audio sound effect when the ball bounces off a paddle.

15. The system shall provide an audio sound effect when a player scores a goal.

16. The system shall provide an audio sound effect when a player wins the game.

17. The system shall provide a control input to adjust the audio output volume.

18. The system shall provide a manual power switch.

19. The system shall indicate power is on via an illuminated indicator.

**Performance Requirements:**

1. The latency from controller input to paddle response shall be less than 10 ms.

2. The nominal audio output signal level shall be -10 dBV (consumer audio level).

3. The maximum audio output signal level shall be +10 dBV.

4. The output volume control gain shall range from negative infinity (i.e., off) to +10 dB.

**Operational Requirements:**

1. Audio capabilities shall require an external commercially-sourced amplified speaker system equipped with a 3.5mm TRS input.

2. The audio output connector shall be a female 3.5mm TRS jack.

3. The system shall require an external power supply compatible with a standard 120 VAC outlet.

4. The system power supply shall provide a fuse for safety.

5. The system shall operate in a typical indoor home/office environment with no precipitation.

6. The system shall operate within the temperature range of 0 to 35 deg C (32 to 95 deg F)

7. The system shall operate in an environment with non-condensing humidity.

**Technical Approach**

| **Example Subunit** |
| --- |
| **Relevant technical issues:**   * A * B |

| **Example Solution Here** | |
| --- | --- |
| **Overview:**   * Cost: * Safety: * Maintainability: * Effectiveness: | |
| **Pros:**   * Pro 1 * Pro 2 * Pro 3 | **Cons:**   * Con 1 * Con 2 * Con 3 |
|

**Hardware**

| **Power** |
| --- |
| **Relevant technical issues:**   * The system shall require an external power supply compatible with a standard 120 VAC outlet. * The system shall indicate power is on via an illuminated indicator. * The system shall provide a manual power switch. * The system power supply shall provide a fuse for safety. |

| **Internal Power supply** | |
| --- | --- |
| **Overview:**  The system will require a power supply to power the galvos, laser, and microcontroller. This could be provided by an internal +/- 15V DC supply alongside a +5V DC supply.   * Cost: 20$ * Safety: Open terminals will need to be covered by a chassis or non conductive coating * Maintainability: N/A * Effectiveness: Provides constant power to the system | |
| **Pros:**   * No need for recharging, constantly power by wall charger * Easy to interface components with | **Cons:**   * The lasers, Running at 5V, will require a step down voltage * Not portable, will ground the unit to a single spot |
|

| **Battery Power Supply** | |
| --- | --- |
| **Overview:**  Due to the use of low power lasers for safety reasons (5mW), the ability to use a battery is not out of the question.   * Cost: 15$ * Safety: Battery will need to be kept within reasonable temperatures to avoid combustion * Maintainability: Battery will need to be replaced periodically due to degradation of battery * Effectiveness: Provides constant power to the system | |
| **Pros:**   * Mobile, allows the unit to be moved without powering down | **Cons:**   * Will require boost converter * Will require additional interface for 15+ 15- voltage terminal * Will require additional hardware to charge battery |
|

| **Controllers** |
| --- |
| **Relevant technical issues:**   * The system shall accept individual input from each player to control the vertical position of their respective paddle. * The system shall provide a control input to start/restart the game. * The latency from controller input to paddle response shall be less than 10 ms. |

| **Bluetooth Controllers** | |
| --- | --- |
| **Overview:**  To provide players with the ability to provide input, bluetooth controllers can be used   * Cost: 30-40$ * Safety: N/A * Maintainability: * Effectiveness: Will provide superior controller support for game | |
| **Pros:**   * Bluetooth controllers provide wireless input from the user and the receiver * Bluetooth controllers provide a comfortable grip, with a variety of buttons * Bluetooth controllers will come prebuilt | **Cons:**   * Bluetooth module on controller required * Bluetooth module on console required * Controllers will need battery power |
|

| **Wired Controllers** | |
| --- | --- |
| **Overview:**  To provide players with the ability to provide input,   * Cost: 5$ * Safety: N/A * Maintainability: Due to its design, wired controllers are more prone to breaking * Effectiveness: Will provide adequate controller support for game | |
| **Pros:**   * Easy to develop and interface with the microcontroller * Easy to replace and repair as needed | **Cons:**   * Chassis for controller will need to be developed * Wired… so no wireless support |
|

| **Motion Control** | |
| --- | --- |
| **Overview:**  Allows the players to use their bodies to control the actions on the game. Like treating the user’s hand as a paddle   * Cost: 100$ * Safety: Swinging and flailing around equipment may cause damage * Maintainability: N/A * Effectiveness: Will provide unique controller support for game | |
| **Pros:**   * Extremely unique and innovative * No controllers needed * Easily understandable controls, just move your hands | **Cons:**   * Will require some way to detect and classify the motion of the body * Will require additional microcontrollers to process the visual information * Expensive compared to other options |
|

| **Projection / Laser Manipulation** |
| --- |
| **Relevant technical issues:**   * The system shall project vector-based video game graphics onto a two-dimensional rectangular surface using a dynamically steered laser beam. * The system shall display a graphical “paddle” for each player * The system shall display a graphical “ping pong ball”. * The system shall animate the motion of the ball to simulate physical ping pong in a manner similar to the Atari “Pong” video game. * The system shall display a graphical boundary indicating solid edges of the playing area (i.e., boundaries that will cause the ball to bounce). * The player scores shall be graphically displayed. |

| **Galvo Motors W/ Mirrors** | |
| --- | --- |
| **Overview:**  Controls the projection of the laser using two Galvo motors with attached mirrors. Each mirror controls a degree of motion for the mirror, totalling to two dimensions of freedom, creating a 2D image   * Cost: 30$ * Power: < ~20 watts * Heat: Console case should be ventilated * Safety: Users should avoid standing within the ROM (range of motion) of the laser(s) * Maintainability: Motors are a vital component of the system, consider having backups * Effectiveness: Provides a cost and power effective method of modifying the direction of the laser | |
| **Pros:**   * Support extremely fast updates to galvo motors * Allows modifying the projection of the laser, without changing aspects of the actual laser module | **Cons:**   * Required additional drivers to control stepper motor * Required a DAC (Digital to Analog) system to convert digital output from the microcontroller to differential analog signal for the Galvo motor drivers |
|

| **Laser(s)** |
| --- |
| **Relevant technical issues:**   * The system shall project vector-based video game graphics onto a two-dimensional rectangular surface using a dynamically steered laser beam. |

| **5mW Single Laser** | |
| --- | --- |
| **Overview:**  A single red/green/blue 5mW laser that is controlled using a laser driver.   * Cost: 5$ * Safety: Low power laser that won’t cause serious damage with minimal contact * Maintainability: lasers burn out over time, consider replacements * Effectiveness: Low power causes insufficient brightness in daylit environments | |
| **Pros:**   * Cheap, Easy to install * Minimal safety concerns * Green lasers provide best visual clarity | **Cons:**   * Dim brightness * Cheaper lasers might have lag when responding to voltage changes |
|

| **High Power Single Laser** | |
| --- | --- |
| **Overview:**  A single red/green/blue laser that is controlled using a laser driver.   * Cost: 30$ * Power: 5mW or above * Safety: High power laser raises serious safety concerns with users * Maintainability: lasers burn out over time, consider replacements * Effectiveness: Highly effective at displaying images in a varying number of environments | |
| **Pros:**   * Provides the best visual clarity * High brightness | **Cons:**   * Raises safety concerns * Might require adequate cooling to combat heating of the unit |
|

| **5mW Multi-Color Laser** | |
| --- | --- |
| **Overview:**  red, green, and blue lasers combined via one way mirrors that are controlled using a laser driver.   * Cost: 30$ * Safety: Low power laser wont causes serious damage with minimal contact * Maintainability: lasers burn out over time, consider replacements * Effectiveness: Low power causes insufficient brightness in daylit environments | |
| **Pros:**   * Provides a spectrum of possible colors compared to a single laser | **Cons:**   * Requires 3 Laser/ Laser Drivers * Requires a system to combine lasers into a single stream |
|

| **Laser Drivers** |
| --- |
| **Relevant technical issues:**   * The system shall modulate the intensity of the beam to ensure individual graphical elements appear separated from one another (i.e., no unwanted “connecting” lines are visible). |

| **TTL (Transistor - Transistor Logic)** | |
| --- | --- |
| **Overview:**  Controls the state of the laser, allowing the unit to be turn on and off by the microcontroller   * Cost: 5$ * Safety: N/A * Switching rate: Microcontroller dependant * Maintainability: Transistors might need cooling to avoid damage * Effectiveness: Simple | |
| **Pros:**   * Cheap and easy to build * Extremely easy to interface with the microcontroller | **Cons:**   * Only allows a laser to be in two states (On or Off) * With 3 colors (RGB), only allows for 8 possible color combinations   + Red, Green Blue   + Cyan Magenta, yellow   + White, Black(off) |
|

| **PWM (Pulse Width Modulation)** | |
| --- | --- |
| **Overview:**  Controls the state of the laser, allows the brightness of the a laser to be between 0(off) and N(on) with N+1 bits of control   * Cost: 20$ * Safety: N/A * Maintainability: Transistors might need cooling to avoid damage * Effectiveness: effective | |
| **Pros:**   * If using 3 colors,Allows for N^3 possible combinations between laser colors   + For example, with 32 bits of accuracy, we can have 32,768 possible color combinations | **Cons:**   * Required a must more complicated driver for each laser |
|

| **Audio Driver** |
| --- |
| **Relevant technical issues:**   * The system shall provide an audio sound effect when the ball bounces off a boundary. * The system shall provide an audio sound effect when the ball bounces off a paddle. * The system shall provide an audio sound effect when a player scores a goal. * The system shall provide an audio sound effect when a player wins the game. * The nominal audio output signal level shall be -10 dBV (consumer audio level). * The maximum audio output signal level shall be +10 dBV. * The output volume control gain shall range from negative infinity (i.e., off) to +10 dB. * The audio output connector shall be a female 3.5mm TRS jack |

| **Teensy Shield** | |
| --- | --- |
| **Overview:**   * Cost: 20$ * Safety: N/A * Maintainability: N/A * Effectiveness: Effective | |
| **Pros:**   * Includes onboard SD card storage * Easy to use | **Cons:**   * Shield format makes physically interacting with some pins difficult |
|

| **Galvo Drivers** |
| --- |
| **Relevant technical issues:**   * The system shall project vector-based video game graphics onto a two-dimensional rectangular surface using a dynamically steered laser beam. |

| **Store Bought Galvo Driver** | |
| --- | --- |
| **Overview:**  A driver unit that uses a differential signal that will be controlled by a microcontroller via some form of hardware link   * Cost: 20$ * Safety: N/A * Maintainability: N/A * Effectiveness: Effective | |
| **Pros:**   * Easy to set up, requires little to no tweaking | **Cons:**   * Requires a 5 -/+ voltage differential analog signal for each motor * Most microcontrollers only have digital output pins, so a DAC would be needed |
|

| **Microcontroller / Computer** |
| --- |
| **Relevant technical issues:**   * The system shall implement a two-player pong-style video game (conceptually patterned after the Atari “Pong” video game). * The system shall keep score for both players. |

| **Teensy** | |
| --- | --- |
| **Overview:**  Teensy provides a central point of control for all other sub modules in the system. The microcontroller shall handle game logic, external input, laser projection, and audio systems   * Cost: 50$ * Safety: N/A * Maintainability: N/A * Effectiveness: Effective | |
| **Pros:**   * Can be coded by a supported IDE * Provides an array of libraries for supported devices * Provides an impressive 600 MHz clock rate | **Cons:**   * Not developed by arduino |
|

| **Arduino** | |
| --- | --- |
| **Overview:**  Arduino boards provide a central point of control for all other sub modules in the system. The microcontroller shall handle game logic, external input, laser projection, and audio systems   * Cost: 50$ * Safety: N/A * Maintainability: N/A * Effectiveness: Effective | |
| **Pros:**   * Can be coded by a supported IDE * Provides an array of libraries for supported devices | **Cons:**   * Limited speeds compared to Teensy lineup |
|

| **Prebuilt microcontroller** | |
| --- | --- |
| **Overview:**  A microcontroller that is preloaded with code that works with a set of galvo motors out of the box.   * Cost: ??? * Safety: N/A * Maintainability: N/A * Effectiveness: Simple | |
| **Pros:**   * Easy to use and setup | **Cons:**   * Does Not allow adequate modification * Does Not have additional external I/O * Hard to find |
|

| **External I/O** |
| --- |
| **Relevant technical issues:**   * The system shall provide a control input to start/restart the game. * The system shall provide a manual power switch. |

| **Simple Buttons** | |
| --- | --- |
| **Overview:**  A Simple set of buttons and knobs to allow for external control of the devices, for example, A toggle switch to control the power of the system, or an led indicator to indicate the power is on.   * Cost: 5$ * Safety: N/A * Maintainability: N/A * Effectiveness: Would provide the bare essentials | |
| **Pros:**   * Easy to set up * Cheap | **Cons:**   * Looks ugly * Would require dedicating pins for specific external actions |
|

| **Touch Screen** | |
| --- | --- |
| **Overview:**  A LCD touchscreen that allows the user to control the device. The LCD allows for a customizable HMI that can be optimized for user experience.   * Cost: 30$ * Safety: N/A * Maintainability: N/A * Effectiveness: Would provide a unique and expandable way to control the system | |
| **Pros:**   * Allows for a near infinite amount of way to control the system * Easy and intuitive to use * Pleasant to look at | **Cons:**   * Would require additional software development to integrate with the system * Additional power consumption from running the screen |
|

| **Smartphone/Tablet** | |
| --- | --- |
| **Overview:**  A tablet or smartphone that allows the user to control the device. The device would be handheld and offer good graphics.   * Cost: N/A * Safety: N/A * Maintainability: N/A * Effectiveness: The user could connect using WiFi or bluetooth from their device | |
| **Pros:**   * Anyone with a smart device could play * Would feel like any other game from the app store | **Cons:**   * Would require app development * People who do not have smart devices could not play |
|

**Software**

| **IDE (Integrated Development Environment)** |
| --- |
| **Relevant technical issues:**   * The system shall implement a two-player pong-style video game (conceptually patterned after the Atari “Pong” video game). |

| **Arduino IDE** | |
| --- | --- |
| **Overview:**   * Cost: Free * Safety: N/A * Maintainability: N/A * Effectiveness: Would allow the user to write and modify code for a varying number of microcontrollers | |
| **Pros:**   * Easy to use * Large number of supported boards * Pre Installed libraries | **Cons:**   * Comes with a proprietary code editor |
|

| **Games** |
| --- |
| **Relevant technical issues:**   * The system shall implement a two-player pong-style video game (conceptually patterned after the Atari “Pong” video game). |

| **PONG** | |
| --- | --- |
| **Overview:**  Pong was originally developed by Allan Alcorn and released in 1972 by Atari corporations. Soon, Pong became a huge success, and became the first commercially successful game.  While simple, pong would showcase the abilities of the laser projection system, while simultaneously allowing a level of player interaction with the system   * Cost: N/A * Safety: N/A * Maintainability: N/A * Effectiveness: Would effectively showcase the abilities of the laser showcase | |
| **Pros:**   * Pong is an overall easy game to program * Would require as little as two inputs from each player * Could run efficiently on most hardware | **Cons:**   * Simple and predictable |
|

| **2D Game Engine** | |
| --- | --- |
| **Overview:**  Rather than primarily focusing on a simple pong game, We could aim to develop a basic 2D Game Engine Framework, that multiple games could be built off of, not just pong   * Cost: N/A * Safety: N/A * Maintainability: Would require extensive documentation * Effectiveness: Would more effectively showcase the abilities of the laser showcase | |
| **Pros:**   * Allows for a array of games to be played on the system   + Breakout   + Space invaders   + Tetris   + Breakout   + Pacman   + Ect. * Allows for a more flexible and dynamic working environment | **Cons:**   * Would take a large chunk of time to develop as opposed to base pong * Would require a varying array of control schemes |
|

| **3D Game Engine** | |
| --- | --- |
| **Overview:**  A 3D engine is not out of the domain of the microcontroller with a decent clock rate.   * Cost: N/A * Safety: N/A * Maintainability: N/A * Effectiveness: Would very effectively showcase the abilities of the laser/galvo assembly | |
| **Pros:**   * Could implement a rudimentary 3D demo of basic shapes | **Cons:**   * Would be a lengthy and complicated development * Would be more difficult to implement user interaction |
|