Mechatronics Project Report

Persistence of Vision Educational Kit with Basic Stamp 2

Vedvyas Danturi - vsd2027

Josephine Odusanya - joo9964

Sven Sunny Kottuppallil - ssk10038

Table of Contents

1. Abstract

This document presents the conceptualisation and development of a Persistence of Vision Educational Robotics Kit. Our objective is to design a mechatronics enabled pre-college level science experiment which will rival the basic robot car kits we see on the market today. A persistence of vision display is a device that creates the illusion of a stable image or text by rapidly moving a set of LEDS in a specific pattern. Using this concept, students will be equiped to explore signal modelling of two types of outputs :- mechanical and optical in a fun and creative way. Our implementation of LED's will change based on the measurement of ambient light as our sensory feedback. In the first stage of the implementation of this project, members of the development team mainly focused on the research of RGB LEDS and it's integration with the Basic Stamp 2. During its development, we used PBasic language programming to develop rudimentary code for control of the motor and the sequence of 6 RGB LEDS. We realize that to improve on optical sensation created by the incident rays, we still need more investment in software and hardware, and to integrate the developed code with an IC that preferably has more than 2KB of memory. This bring us to the second stage of the project, where we implement an IC 4.1 solely as the LED driver, as it can directly address the integrated drivers embedded within Adafruit Neopixel Ring. The purpose of the two stages is to show students the scalability of such projects and promote problem-solving, critical thinking and innovation.

Keywords: Basic Stamp 2, Persistence of Vision (POV), LEDs, Educational Kit

2. Introduction

In this report, the aim is to create a kit that teaches the concepts of memory efficient programming, gearing and mechanical structures via Persistence of Vision display as well as the introduction to components like the ambient light sensor (photodiode), potentiometer, hall effect sensor, DC motor and finally, the Basic Stamp 2.

By using the Basic Stamp 2, students gain experience in programming a microcontroller to control the timing and synchronization of the RGB LED array, which is essential for creating the dynamic light patterns needed for POV. The incorporation of the ambient light sensor allows for the detection of ambient light intensity, providing immediate feedback that can be used along with the digital potentiometer as the user interface to adjust light brightness and control parameters. In darkness, it will turn the light up lower so it does not hurt our eyes while in brightness, it turns it up higher to show the effect clearly.

The Hall effect sensor and DC motor add a dynamic element to the experiment, enabling the rotation of the LED array to simulate motion. The Hall effect sensor allows us to calculate the motors RPM, which can be used to synchronize the LED array with the motor's rotation, enhancing the POV effect.

The significance of this project lies in its interdisciplinary nature, combining aspects of electronics, programming, physics, and engineering. It encourages critical thinking, problem-solving, and creativity, helping students develop technical skills and an understanding of how various components can work together to create a functional system. Moreover, the experience gained from this project will be essential in fields ranging from digital media to robotics and product design.

2.1 Research Background and Significance

A reoccuring problem amongst Robotics enthusiast has to do with the cost of the materials. It is said to be out-of-date, difficult to use or sometimes too expensive or scarce to acquire. With the growing field of technology too, people are itching for ways to diversy their portfolio. With this in mind, we came up with something that is both educational and different from what we regularly see on the market. Thus we introduce you to Persistence of Vision Educational Robotics kit.

What is persistence of vision?

The ability to recall information, whether visual or otherwise, immediately after it has been presented differs from person to person. **Persistence of Vision (POV)** takes advantage of that, it being an optical phenomenon where the human eye perceives a visual image for longer than its actual duration.[1]

It was first defined by English-Swiss physicist Peter Mark Roget [2] in the nineteenth century and its phenomenon can be linked back to many inventions made to exploit persistence of vision and the phi phenomenon to create a false sense of moving objects. In this project, instead of keeping all the LEDs continuosly active, we will implement flicker fusion threshold where rapid flickering to simulate constant illumination.[3] The two concepts form the basis of motion perception. This rapid flickering will give the appearance of steady light which ha an added benefit of reducing the overall power consumption.

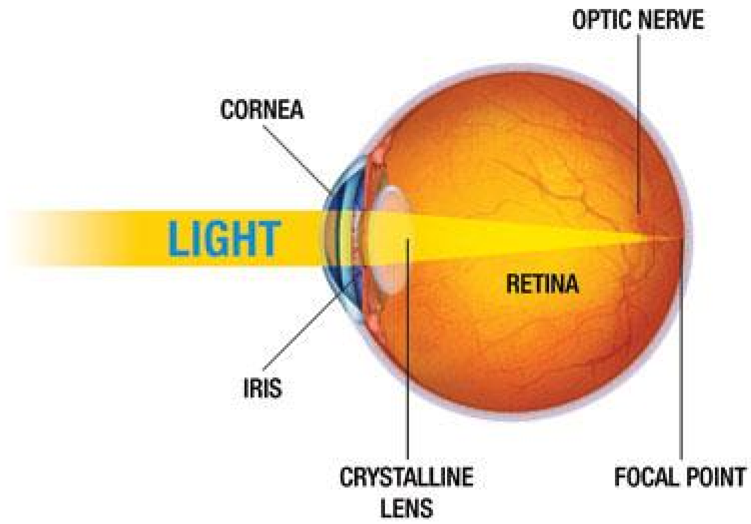


Figure 1: How the eyes process light[4]

POV is only possible because the human eye can only process 10 to 12 seperate images per second, retaining an image for up to a fifteenth of a second. As the subsequent image replaces it in this period of time, it will create the illusion of continuity[5].

3. Related Work

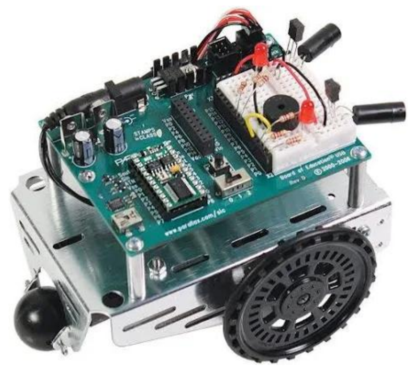


Figure 2: BoeBot Kit

Parallax BoeBot Robot Kit:
- Boring
- Expensive
- Many discontinued components

Figure 3: Arduino Science Kit

Arduino Science Kit:
- Expensive
- Limited learning ability

Figure 4: POV Product Label

Persistence of Vision Educational Robotics Kit:

- Fun
- Unique
- Inexpensive compared to competitors

4. Hardware Design and Working Principle

Stage I

Hardware Components

Qty	Components
1	Basic Stamp 2
1	DC Motor
1	Hall Effect Sensor
1	Digital Potentiometer
6	RGB LEDs
1	Ambient light sensor
1	Magnet
1	Slip ring
~pcs	3D printed motor mount

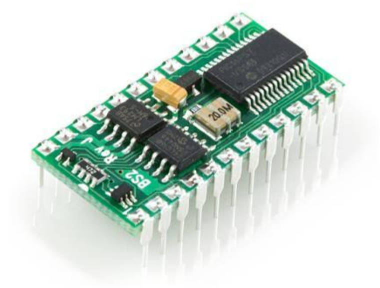


Figure 5: BS2 module

Basic Stamp 2 (BS2): The BS2 acts as the primary controller for the system, processing data from sensors (like the photodiode) and controlling the RGB LEDs to create the desired Persistence of Vision (POV) patterns.

Figure 6: DC Motor

DC Motor: The DC motor drives the rotation of the LED array, achieving the high-speed spinning necessary to produce the POV effect.

Figure 7: Hall Effect Sensor

Hall Effect Sensor: This sensor detects the position of the stationary magnet, providing synchronization signals to ensure the LED patterns align accurately with the motor's rotation.

Figure 8: Digital Potentiometer

Digital Potentiometer: Used in Stage 1, the potentiometer allows manual control of LED brightness and system parameters by adjusting resistance.

Figure 9: RGB LED

RGB LEDs: These LEDs form the core visual component, emitting light in programmable colors and patterns to create the POV effect as the array spins.

Figure 10: Ambient Light Sensor

Ambient Light Sensor (Photodiode): The photodiode measures ambient light levels and sends the data to the BS2, which adjusts the brightness of the LEDs for optimal visibility under varying lighting conditions.

Figure 11: Magnet

Magnet: The magnet works with the Hall effect sensor to provide positional feedback, enabling precise synchronization of the LED patterns with the rotation of the motor.

Figure 12: Slip ring

Slip Ring: The slip ring allows continuous electrical connection to the rotating LED array, enabling power and data transfer without tangling wires during rotation. One consideration to note is with high RPMs, the wires tend to burn. That is why people develop their own slip rings. Another avenue for innovation!

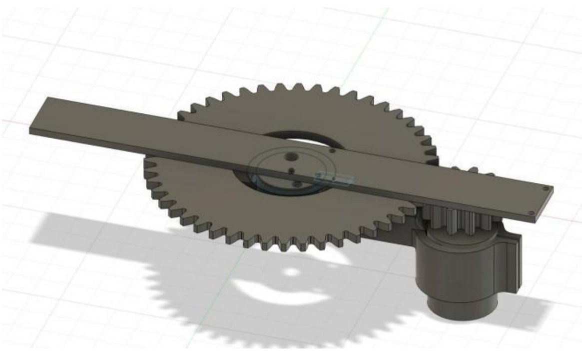


Figure 13: 3D LED Mount

3D Printed Motor Mount (for stage I): This custom mount securely holds the motor in place, ensuring stability during high-speed rotations and alignment of the POV display components.

Figure 14: Pushbutton

Killswitch: With a simple pushbutton, users can easily press it which would send a low pulse to all the connected components, effectively shutting it off.

4.1.1 Working principle

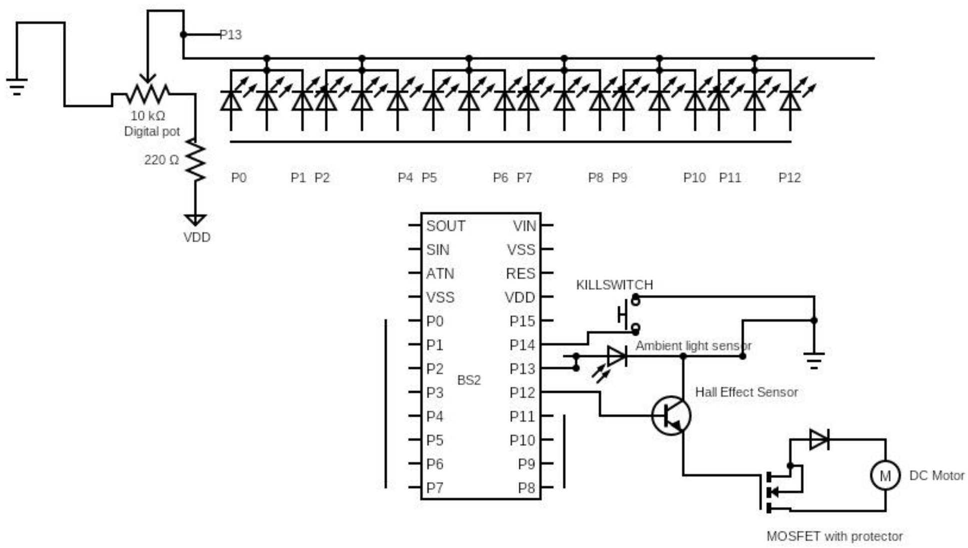


Figure 15: Stage I Circuit Diagram

In this stage, a Persistence of Vision (POV) display is created and controlled by the Basic Stamp 2 (BS2) microcontroller. Six RGB LEDs are connected in series and spin at x </= 1800 rotations per second using a 16k RPM motor. The BS2 controls the LED brightness and patterns through programming (see Appendix A), while a Hall effect sensor detects the passing magnet, changing the LED patterns in real-time. Additionally, a photodiode feeds ambient light data to the BS2, allowing it to adjust the LED light intensity based on the surrounding light conditions. This setup creates dynamic visual effects using rapid LED flashing synchronized with motor speed and

sensor input. We made use of a 4:1 gearing to get 4k RPM output out of the 16k RPM motor and further control the PWM through a MOSFET gate.

4.1.2 Results

Below is a successful implementation of the components to create a visually aesthetic ring of light (better seens in person).

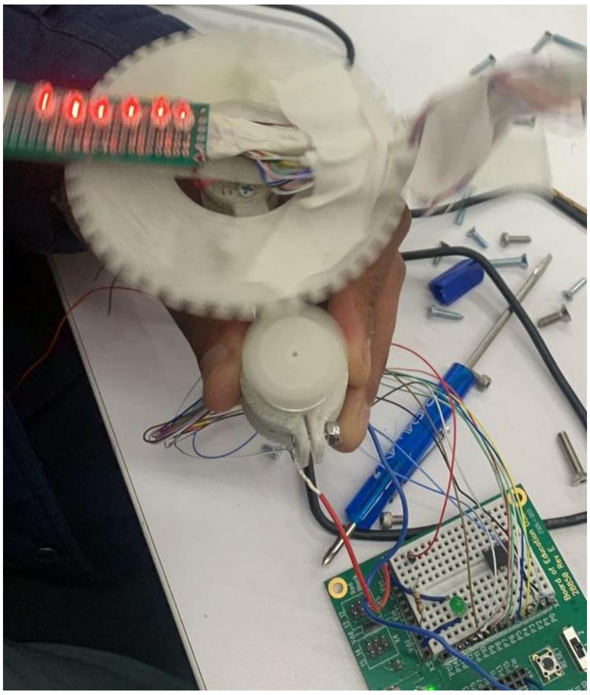


Figure 16 : Prototype of Stage I

4.2 Stage II

Below is an updated list of components being used.

Qty	Components
1	Basic Stamp 2
1	DC Motor
1	Hall Effect Sensor
1	~~6 RGB LEDs~~ Adafruit 24 LED Neopixel Ring
1	Ambient Light Sensor
3	Magnet
1	Slip ring
~	3D printed motor mount
1	ADC
1	Digital potentiometer
1	555 Timer
1	Teensy 4.1

Figure 17: ADC

ADC (Analog-to-Digital Converter): Converts analog signals (e.g., from the photodiode) into digital data for processing by the BS2.

Figure 18: 555 Timer

555 Timer: Potentially used for generating precise timing signals or PWM control.

Figure 19: LED Ring

Adafruit NeoPixel Ring : The NeoPixel Ring integrates 24 individually addressable RGB LEDs, enhancing the display's resolution and scalability compared to the original 6 RGB LEDs. This compact design simplifies wiring while enabling a wider range of colors and patterns, making the POV effects more vibrant and detailed.

Figure 20: WS2812b Chip

Special note on WS2812b SMD Adressable RGB LED:

The WS2812B SMD Addressable RGB LED is a powerful and versatile component for creating dynamic lighting effects in projects. However, its direct integration with the Basic Stamp 2 (BS2) microcontroller presents significant challenges:

-Timing Requirements: The WS2812B requires precise timing for data transmission, typically in the range of microseconds1. The BS2, with its PBASIC interpreter, may not be able to meet these strict timing requirements consistently.

-Protocol Complexity: The WS2812B uses a single-wire protocol that requires carefully timed pulses to transmit data. Implementing this protocol efficiently in PBASIC can be challenging due to the language's limitations.

-Limited Resources: The BS2 has limited memory and processing power compared to more modern microcontrollers. This can make it difficult to handle the data processing required for complex LED animations or long LED strips.

To overcome these incompatibility issues, we considered using a dedicated LED driver chip (Figure) as an intermediary between the BS2 and the WS2812B LEDs. This approach would allow the BS2 to focus on higher-level control while offloading the timing-critical operations to a more suitable device.

Teensy IC 4.1 : The Teensy IC 4.1 replaces the digital potentiometer as the primary driver for the Adafruit NeoPixel Ring, providing advanced computational power and flexibility. It enables precise control of the LEDs, allowing for intricate patterns, smooth transitions, and rapid updates to the display, essential for creating detailed Persistence of Vision (POV) effects. Students should note any IC could be used for this advanced processing compatible with the WS2812b LED found in the Adafruit Neopixel ring, but we chose this one for its simplicity and price point.

Figure 21: Teensy 4.1 LED Driver

3D Printed Mount (for stage II):

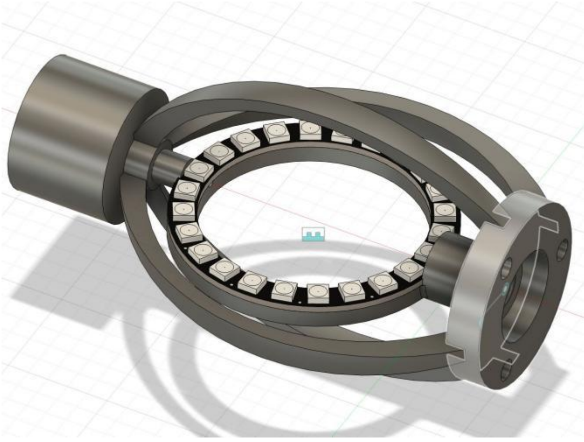


Figure 22 : 3D LED Mount

4.2.1 Working principle - Stage II

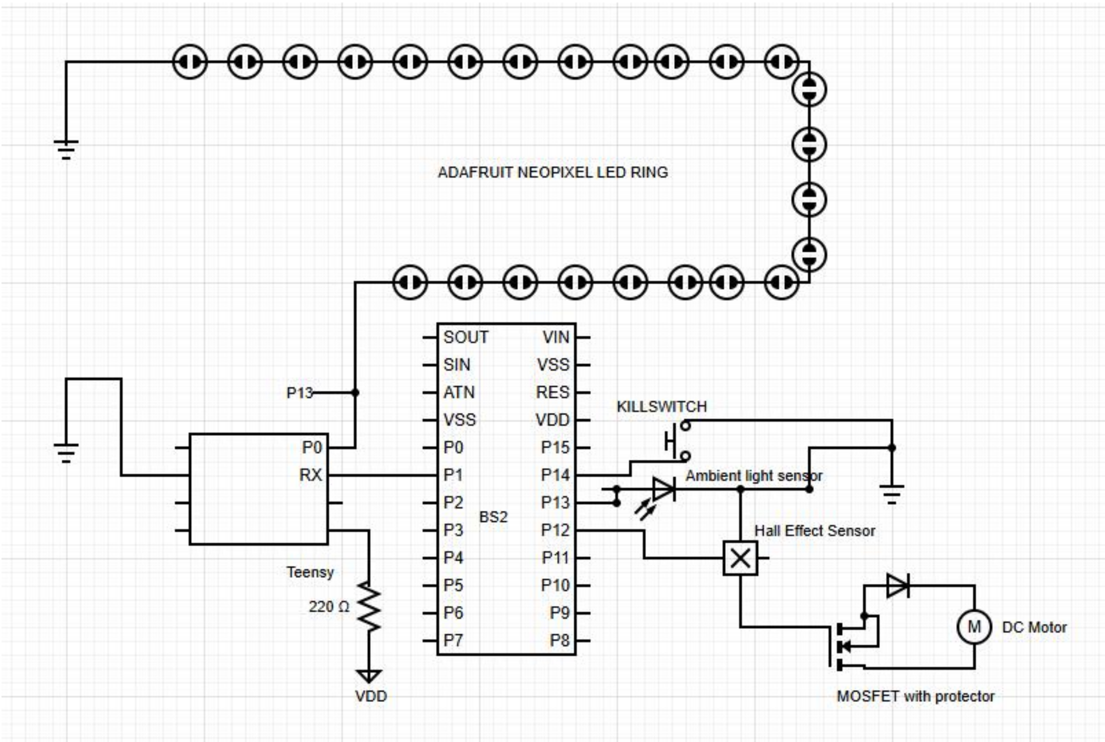


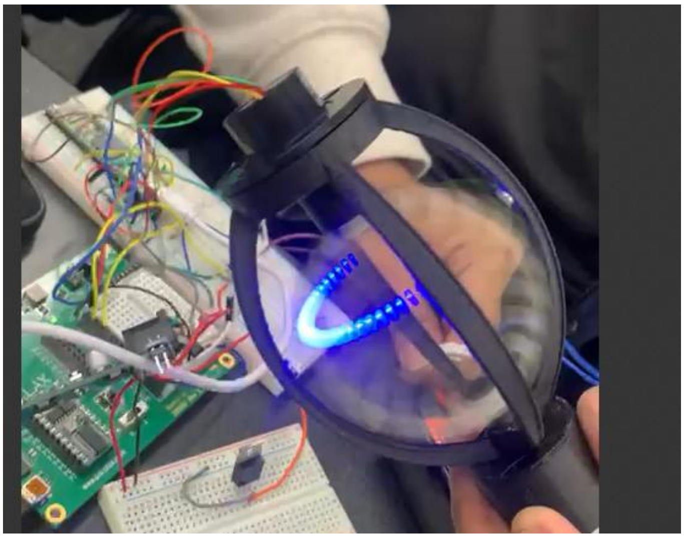
Figure 23: Rough Circuit Diagram

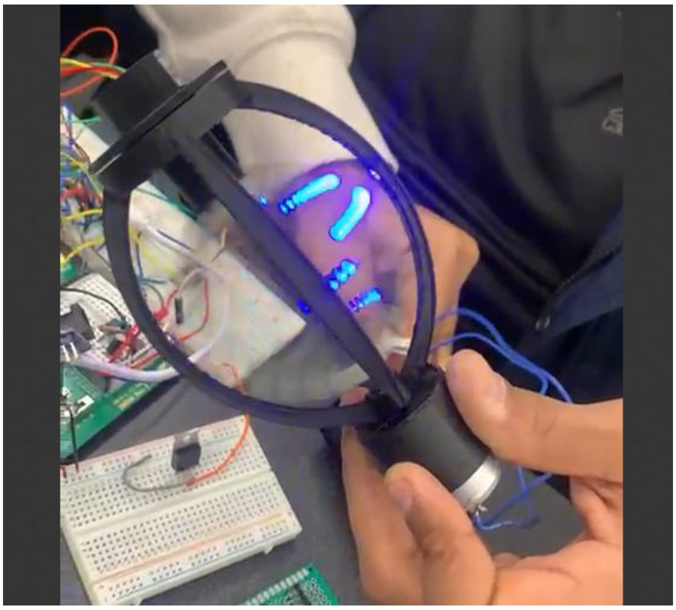
Highlight
Basic Stamp 2 Intergration with Teensy IC 4.1 : It is important to note that the Teensy is purely being used as a LED driver. All the user interface, actuator control and other instructions will still be sent or received by the BS2.

In Stage 2 of this project, the scalability of the Persistence of Vision (POV) display is explored by incorporating the Adafruit NeoPixel Ring, which consists of 24 individually addressable LEDs, and replacing the potentiometer with the Teensy 4.1 microcontroller to drive the LED array. The photodiode is used to measure ambient light levels and control the light intensity of the LEDs. The BS2 processes the ambient light information and uses it, along with control signals, to define and adjust the LED patterns on the NeoPixel Ring. The Hall Effect sensor continues to play a critical role by synchronizing the motor speed, ensuring the LEDs spin at the correct rotational speed for optimal POV effect. The Teensy 4.1 microcontroller provides enhanced processing power, allowing for more complex and scalable control of the LED patterns, enabling smoother transitions and more intricate visual effects compared to Stage 1. This setup demonstrates the potential to scale the POV display by increasing the number of LEDs while maintaining synchronization between the LED patterns and the motor speed.

4.2.2 Results

Successfully managed to create a simple display.





Figures 24 : Prototype of Stage 2

4.3 Bill-of-material

Qty	Parts	Cost/item ($)
10	RGB LEDs	0.99
1	Micro Motor DC 7V 6700-6900RPM Motor	8.99
2	Slip rings	8.00
1	MOSFET with protector	3.66
1	Adafruit Neopixel Ring	11.50
1	Basic Stamp 2 module	49.00
1	Ambient light sensor (Photodiode)	2.00
1	Digital potentiometer	1.52
1	Electronic Trimmer 1M Ohm	1.00
1	Electronic Trimmer 100K Ohm	1.00
1	Relay Module	1.99
1	LED driver (Teensy)	29.60
1	Small DC Motor	4.99
	Total	125.10

Advantages

- ✓ Power Efficiency: The rapid flickering used to simulate constant illumination reduces overall power consumption compared to keeping all LEDs continuously active[5].

- ✓ Educational Value: The kit provides hands-on experience with various concepts and components, including memory-efficient programming, gearing, mechanical structures, and electronic sensors, offering a comprehensive learning tool for students.

- ✓ Practical Application of Visual Perception: The product demonstrates the practical application of visual perception principles, such as POV and flicker fusion, which are critical in modern display technologies and visual effects.

Disadvantages

- × Individual Perception Variability: The effectiveness of the POV display may vary among users due to differences in individual flicker fusion thresholds, potentially affecting the quality of the visual experience for some users [5].
- × Potential for Visual Discomfort: Rapid flickering, if not properly calibrated, could cause visual discomfort or fatigue in some users, especially during prolonged use.
- × Complexity for Beginners: The integration of multiple concepts and components (e.g., programming, sensors, mechanical structures) may present a steep learning curve for beginners, potentially requiring additional guidance or resources.

4.4 Hardware Debugging

This project encountered a few setbacks which we will briefly discuss.

Motor slipping off 3D mount:- To solve this issue, we adjusted the parameters of the 3D model and reprinted to account better for allowance but also give a snug fit.
Breaking 3D mount: Initially 3D print was rather fragile but we chaalk that up to maintenance state of the 3D printer. With more iterations however, the design will improve.

5. Software Design and Working Principle

5.1 Mathematical Background of POV

1/10 of a second so 10Hz for POV; for smoother illusion, monitors update at 30hz, same logic to get rotation speed close to 30RPS which is 1800rpm, if we have only one side , since we have a ring, it covers 2 sides, so we would be ok with 900RPM.

5.2 Code flowchart

Stage I

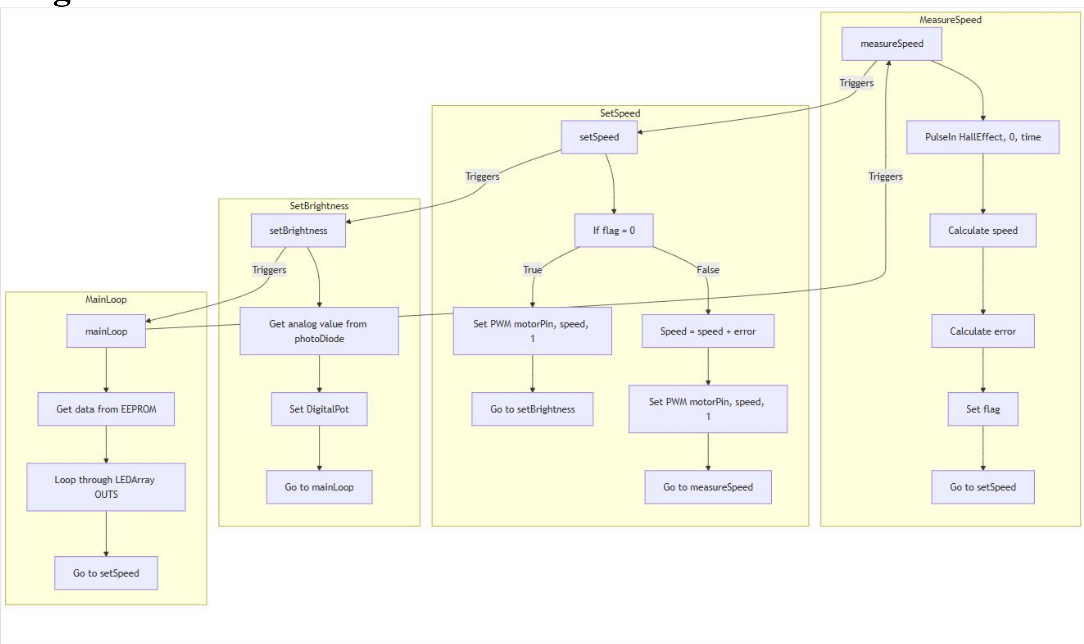


Figure 25: Stage I Rough Code Flowchart

Stage II

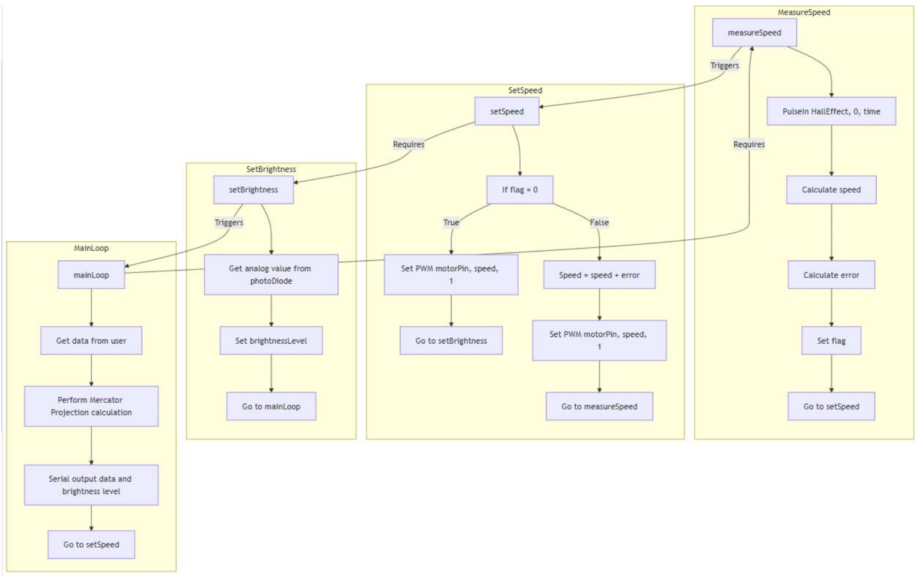


Figure 26: Stage II Rough Code Flowchart

The detailed BS2 program can be found in the appendix.

5.2.1 Proportional Control Algorithm

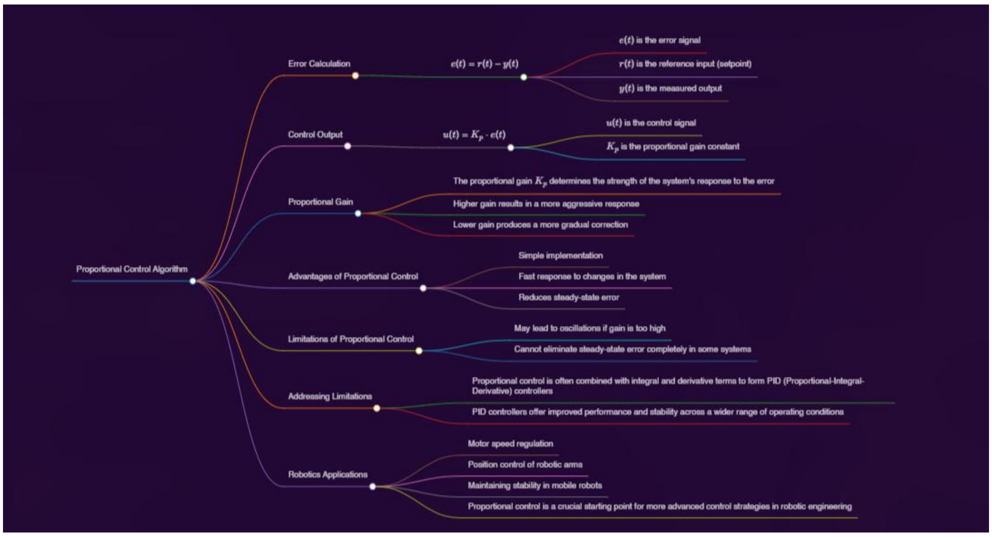


Figure 27: PID Flow

The proportional control algorithm is a key component in feedback control systems used here. It works by applying a correction proportional to the error between the desired and actual output. The algorithm calculates an error signal $e(t)=r(t)-y(t)$ and generates a control output $u(t)=Kp*e(t)$, where Kp is the proportional gain. This simple yet effective method offers fast response and reduced steady-state error, but may cause oscillations if the gain is too high. While it can't completely eliminate steady-state error in some systems, it serves as a foundation for more advanced control strategies like PID controllers.

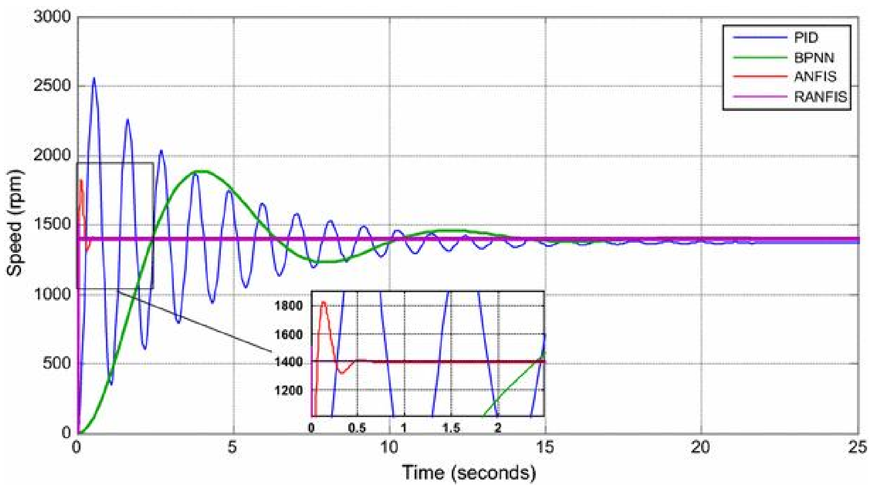


Figure 28: RPM Graph

5.3 Software Debugging

A huge challenge was ensuring the BS2 EEPROM memory was not exceeded. We solved this in stage 2 by implementing the Teensy 4.1 as an LED driver.

6. Persistence of Vision Robotics Educational Kit

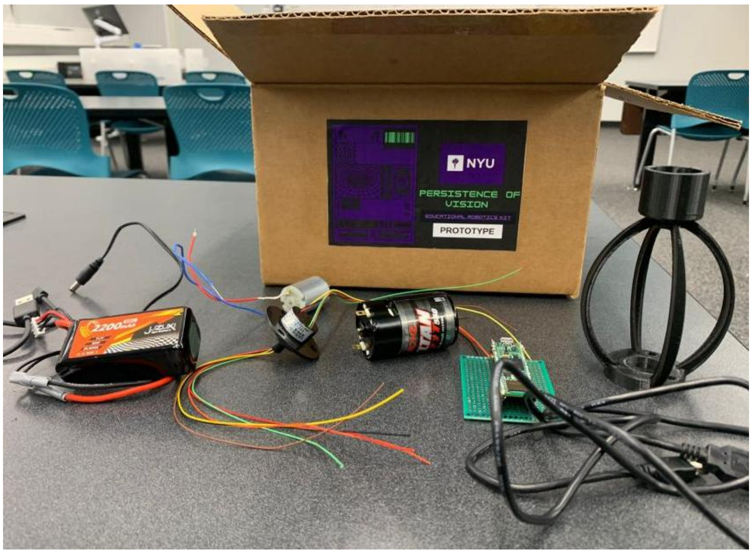


Figure 29: POV Product Kit

6.1 Product Description:

The **Persistence of Vision Robotics Educational Kit** is a cutting-edge learning tool designed to teach students foundational and advanced concepts in electronics, programming, and robotics through hands-on experimentation. Building on the proven success of platforms like the Boe-Bot Robot, this kit offers an immersive experience in developing dynamic displays using the phenomenon of persistence of vision (POV). By following detailed instructions and using modular components, students will learn to assemble and program a spinning LED array that creates stunning visual effects synchronized with motor motion and environmental data. No prior programming or electronics experience is required, making the kit accessible for beginners while still challenging for advanced users.

6.1.1 Kit Overview:

This kit guides students through constructing a functional POV display using components like the BASIC Stamp 2 microcontroller, RGB LEDs, sensors, and motors. The educational journey spans multiple stages, from basic assembly to advanced programming and hardware integration. The projects build incrementally, providing a comprehensive introduction to mechatronics, control systems, and sensor-based feedback mechanisms. Students will engage in tasks such as wiring circuits, tuning source code, and integrating real-time data from sensors to control LED brightness and patterns.

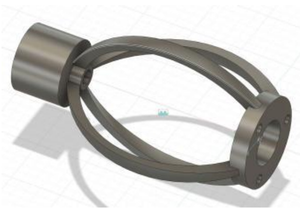
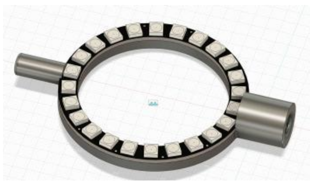
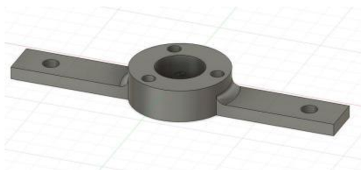
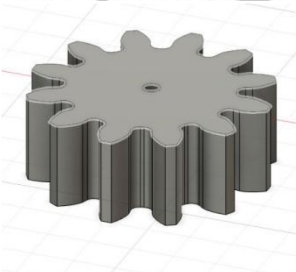
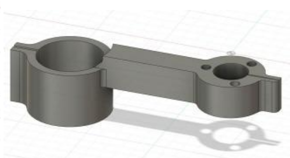
The complete set of projects takes approximately 50 hours to complete, making it ideal for classroom use, robotics clubs, or STEM workshops. Designed for students aged 13 and up, this kit equips learners with skills applicable to fields like robotics, computer science, and engineering.

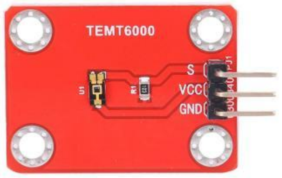
6.1.2 Key Features of the Persistence of Vision Robotics Educational Kit:

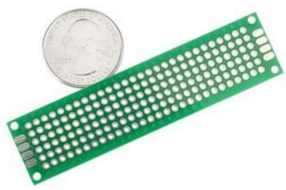
- **Beginner-Friendly:** No programming experience is required; the included guides provide clear, step-by-step instructions.
- **Modular Design:** Components like the BASIC Stamp 2 and Adafruit NeoPixel Ring are reusable and compatible with a variety of robotics and electronics projects.
- **Hands-On Learning:** Exposed circuitry and solder-free breadboard connections allow students to experiment with custom circuits.
- **Dynamic Programming:** Introduces concepts of microcontroller programming, such as PWM control, sensor integration, pattern generation using PBASIC and Teensy 4.1 coding.
- **Autonomous Functionality:** Hall Effect sensors, ambient light sensor, and environmental data enable synchronization and adaptive behavior.
- **Expandable:** Additional sensors and hardware modules can be integrated to explore further applications.
- **Affordable:** Priced for accessibility, with all essential hardware and software included.

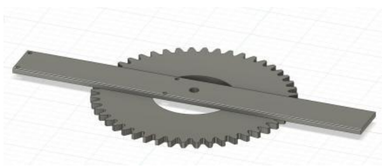
6.1.3 Kit Contents:

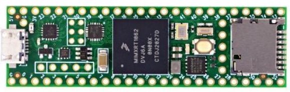
- Basic Stamp 2 microcontroller module
- Adafruit NeoPixel Ring (Stage II upgrade)
- DC Motor with slip ring for continuous power to the spinning LED array
- Hall Effect sensor and photodiode for synchronization and ambient light sensing
- RGB LEDs (Stage I) for foundational POV effects
- Teensy 4.1 microcontroller for advanced pattern generation (Stage II)
- 3D-printed motor mounts for stability and alignment
- All necessary resistors, wires, and hardware for assembly

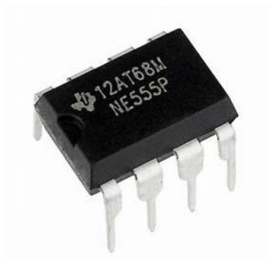














6.1.4 Cost Analysis for Mass Production

Component	Estimated Cost (USD)
Basic Stamp 2	$25.00
DC Motor	$5.00
Hall Effect Sensor	$1.50
Digital Potentiometer	$2.00
RGB LEDs (5 pcs)	$1.00
Ambient Photodiode	$0.75
555 Timer	$0.50
MOSFET with protection	$1.50
Magnet	$0.50
ADC	$0.98
555 Timer	$0.98
Slip ring	$3.00
3D printed motor mount	$2.00
Teensy 4.1	$22.00
Adafruit 24 LED Neopixel Ring	$15.00
Total	$81.71

This cost analysis for mass production is based on estimated bulk pricing for components. The Basic Stamp 2, while traditionally priced at 49 for individual units, can be obtained for around 25 in large quantities1. The DC motor with encoder is estimated at $5, considering bulk pricing for similar motors.

The Teensy 4.1 and Adafruit Neopixel Ring represent significant portions of the total cost due to their advanced features. The 3D printed motor mount cost is an estimate based on material and production costs at scale.

It's important to note that actual costs may vary based on:

- Negotiated supplier contracts
- Market fluctuations in component prices
- Potential design optimizations for mass production
- Shipping and handling costs

Additionally, the total cost could potentially be reduced by:

- Exploring alternative microcontrollers to the Basic Stamp 2 and Teensy 4.1
- Optimizing the LED configuration
- Sourcing components from different suppliers

7. Conclusion

The Persistence of Vision Robotics Educational Kit provides students with practical experience in robotics and programming, fostering critical thinking and problem-solving skills. It introduces them to real-world applications of electronics and microcontrollers, inspiring future careers in STEM fields. With this kit, learners can explore the intersection of science, technology, and creativity, making it a versatile tool for both education and innovation. If they like, they could even adjust the code to show a images too!

8. References

[1] https://www.masterclass.com/articles/persistence-of-vision-explained
[2] https://garagefarm.net/blog/persistence-of-vision-explained-what-is-persistence-of-vision#:~:text=Peter%20Mark%20Roget%2C%20famous%20for,later%20be%20used%20in%20the
[3] https://pmc.ncbi.nlm.nih.gov/articles/PMC8537539/
[4] https://global.samsungdisplay.com/28889/
[5] https://nkcf.org/about-keratoconus/how-the-human-eye-works/
[6] https://www.parallax.com/product/boe-bot-robot-kit-usb/
[7] https://www.sciencedirect.com/topics/engineering/proportional-control
[8] https://www.electronics-tutorials.ws/systems/proportional-control.html
[9] https://www.ni.com/en/shop/seamlessly-connect-to-third-party-devices-and-supervisory-system/the-importance-of-proportional-control.html
[10] https://www.instructables.com/POV-Globe/

9. APPENDIX

All codes used feature here.

BS2 Integration

```
'{$STAMP BS2}
'{$PBASIC 2.5}

hallPin PIN 15 'for digital input of hall sensor
potPulse PIN 0 'for digitalPot adjusting to control pwm which inturn controls motor
upDown PIN 1 'for direction of adjustment of pot
counter VAR WORD 'for how many pulses to give
p CON 12 'multiplier for error

halfTime VAR WORD 'storing time taken by hall
desireTime CON 16500 'our required rpm

errorOK CON 500  'allowable error
errorNow VAR WORD 'current error


speedControl:
 PULSIN hallPin, 1, halfTime 'gives us amount of time taken to go from one magnet
to another
 IF halfTime < desireTime THEN  'speed is overshooting
  errorNow = desireTime - halfTime
  IF errorNow > errorOK THEN
  HIGH upDown                   'wiper goes towards the connected terminal lowering
resistance
  errorNow = errorNow ** p
  FOR counter = 0 TO errorNow
   PULSOUT potPulse, 1 'lower resistance means lesser duty cycle from 555, so
lowering the speed
   PAUSE 1
  NEXT
  GOTO speedControl
  ENDIF
 ELSEIF desireTime < halfTime THEN 'speed is undershooting
  errorNow = halfTime - desireTime
  IF errorNow > errorOK THEN
  LOW upDown        'wiper goes away from terminal increasing resistance
  errorNow = errorNow ** p
  FOR counter = 0 TO errorNow
   PULSOUT potPulse, 1 'higher resistance means higher duty cycle from 555, so
increasing the speed
```

```
  PAUSE 1
 NEXT
 GOTO speedControl
 ENDIF
ENDIF
GOTO takeBrightness

luminosity VAR BYTE 'for analog Value of voltage by photoDiode
CS PIN 4 'adc chip Select
CLK PIN 3 'adc clk
Datain PIN 14 'adc dataPin
takeBrightness:
HIGH CS
LOW CS
LOW CLK
PULSOUT CLK, 210
SHIFTIN Datain,CLK,MSBPOST,[luminosity\8] 'getting the value
GOTO LedPattern

climateMap VAR BYTE(12) ' initiates 12-byte array, for 12 leds in one half of the ring
LedPattern:
climateMap(0) = %00011111
climateMap(1) = %00110111
climateMap(2) = %00111011
climateMap(3) = %01111010
climateMap(4) = %01111010
climateMap(5) = %00111100
climateMap(6) = %00011100
climateMap(7) = %00011000
climateMap(8) = %00011000
climateMap(9) = %00001000
climateMap(10)= %00000100
climateMap(11)= %00000100
climateMap(12)= %00000000
SEROUT 13, 9600, [STR climateMap\12, luminosity] ' transmits data to teensy
GOTO speedControl
```

Teensy IC Sample code

```
#include <FastLED.h>

#define LED_PIN     2
#define NUM_LEDS    24
#define BRIGHTNESS  125
#define LED_TYPE    WS2812
#define COLOR_ORDER GRB
CRGB leds[NUM_LEDS];

void setup() {
```

```
  FastLED.addLeds<LED_TYPE, LED_PIN, COLOR_ORDER>(leds,
NUM_LEDS).setCorrection(TypicalLEDStrip);
  FastLED.setBrightness(BRIGHTNESS);
}

void loop() {
  for(int pos = 1; pos<NUM_LEDS; pos++){
    // turn the previous LED off and set the current LED to white:
    leds[pos-1] = CRGB::Black;
    leds[pos] = CRGB::Blue;
    FastLED.show();

    delay(500); //control delay for different patterns
  }
  leds[NUM_LEDS -1] = CRGB::Black; //turning last led off
}
```