Design of a Simple Laser Guidance System Using a Quadrant Photodiode

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Abstract – **This report describes the design, assembly, and performance of a simple *laser guidance system*. The system utilized a *quadrant photodiode* and accompanying amplification circuitry to detect the position of incident light from a laser and oriented itself toward the laser using two servo motors.**

I. INTRODUCTION

The goal of this project was to build a simple, breadboard-based laser guidance system. The group was interested in the variety of applications that laser guidance systems have, from simple home devices such as robot vacuum cleaners to military technology such as missile guidance systems. The group explored how these laser guidance systems function, then developed a simple system on a breadboard using commercially available parts along with original 3D-printed parts, printed circuit boards, and software. The objectives of this system were the following: (1) collect light intensity data using a quad photodiode; (2) convert the intensity data into X and Y coordinates used to determine the direction of a light source (laser); (3) orient the quad photodiode in the direction of the light source using two servo motors for pitch and yaw control. The system also mapped spatial data to an organic light-emitting diode (OLED) display on the breadboard and an external plot on a personal computer (PC) for visualization.

II Materials

A. OPR5925 Quad Photodiode

The group considered two units for the quadrant photodiode: (1) TT Electronics OPR5925; (2) Thorlabs PDQ80A. Ultimately, the group chose the OPR5925 for its affordability. At roughly $7, the OPR5925 was significantly less expensive than the $570 Thorlabs PDQ80A. The OPR5925 is shown in Figure 1 and the Thorlabs PDQ80A is shown in Figure 2.

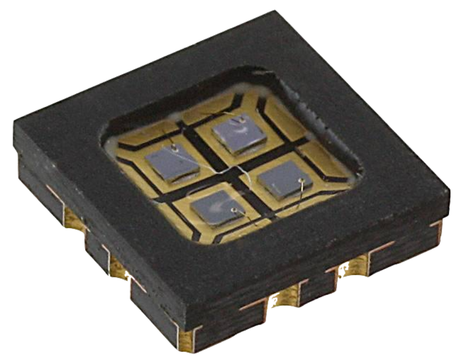

Figure 1. OPR5925 Quadrant Photodiode

Figure 2. Thorlabs PDQ80A Quadrant Photodiode

Additionally, the OPR5925 was more compact than the Thorlabs unit. Each of the four photodiodes on the OPR5925 have an area of 0.75 mm^2. The overall unit offers a minimum responsivity of 0.45 A/W at its peak wavelength of 890 nm. A plot of relative responsivity is provided in Figure 3.

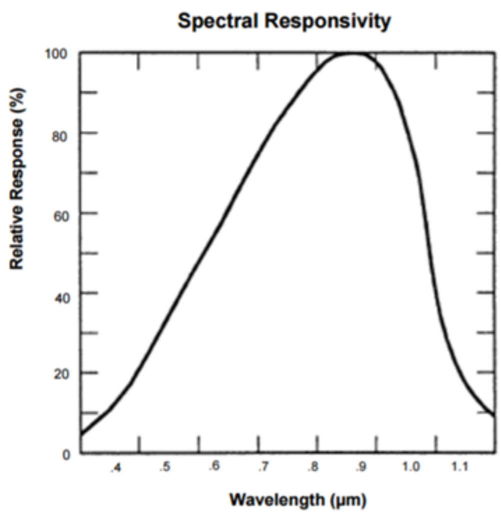

Figure 3. OPR5925 Relative Responsivity

However, the OPR5925's compact design lacked the inclusion of transimpedance amplifiers. As a result, a separate breadboard was required to assemble four transimpedance amplifiers. In addition, a breakout board was needed to interface the surface mount quadrant photodiode with the breadboard. This breakout board is discussed further in *Section III. Design of OPR5925 Breakout Board*.

B. Additional Electronic Components

Additional electronic components were required to monitor the OPR5925, orient the device, and output the status. The Seeeduino XIAO SAMD21 microcontroller was chosen for its suitable pinout and compact size. The quad operational amplifier LM324N was chosen to create four transimpedance amplifiers. A 128x64 pixel OLED display was utilized to display the position of the incident light on the OPR5925. Two SG90 servo motors were implemented to orient the photodiode assembly described in *Section II.C Base and Photodiode Assemblies.* The power to the servo motors was provided by an adjustable 3.3 V - 5 V voltage regulating board.

C. Base and Photodiode Assemblies

Two assemblies were used to house the two SG90 servo motors and the OPR5925. The base assembly housed the yaw control motor and consisted of a modified version of the arm base included in the "EEZYbotARM" design, published by the user theGHIZmo on *Instructables* [1]. A rendering of the design is included in Figure 4.

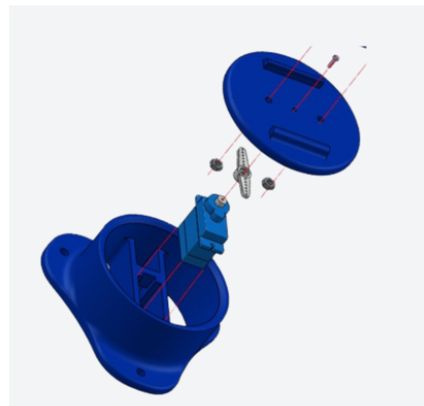

Figure 4. Rendering of the base assembly

Mounted atop the base assembly was the photodiode assembly, as seen in the rendering in Figure 5.

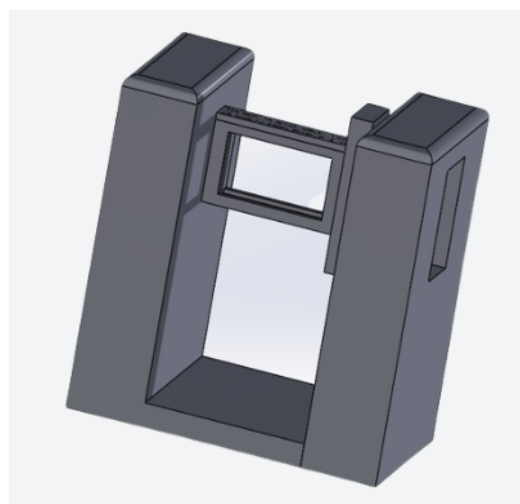

Figure 5. Rendering of the photodiode assembly

The photodiode assembly was designed in SolidWorks, using the base (Figure 4) as a reference. The hollow frame in the center housed the photodiode breakout board, shown in Figure 7. The pitch control servo was housed in the right vertical tower of the assembly. The photodiode assembly was mounted to the base assembly via a friction fit between the two ridges atop the base assembly, shown in Figure 4.

As the SG90 servo motors were limited in their torque output, both the base assembly and photodiode assembly were designed with cutouts that snuggly fit the servo motor arms. Such a design ensured that maximum torque was available for yaw/pitch control.

D. Lens

The *LONGWIN* 2.5 inch hemispherical lens was used to direct light from the laser source towards the OPR5925. This ensured that the laser input was directed toward the active regions of the quad photodiode from a wider range of angles. It is important to mention that this “lens” was simply a paperweight designed to be a magnifying glass. This device was chosen for its affordability (~$10) and availability. If the group had more time to conduct the project, a more sophisticated lens with a smaller radius and a greater ability to focus the beam onto the sensor would have been chosen. A simple custom mount was designed to hold the lens, centering its output on the photodiodes. This mount was separate from the base/photodiode assemblies due to its significant mass that would have overloaded the servos.

III. Design of OPR5925 Breakout Board

As the OPR5925 is a surface mount device, a breakout board was required to interface the quad photodiode with the breadboard discussed in *Section IV. Breadboard Assembly.* The breakout board shown in Figure 6 was designed in Autodesk Eagle using the component dimensions provided by the OPR5925 datasheet.

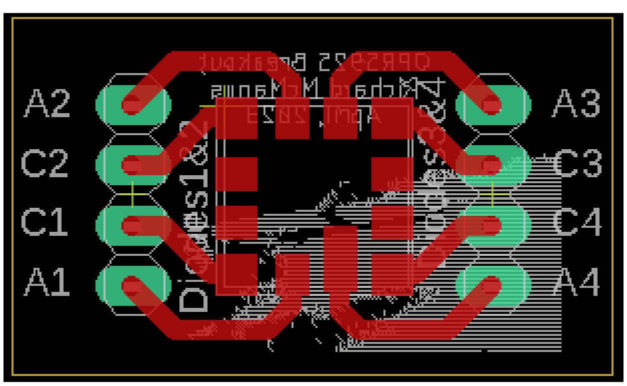

Figure 6. OPR5925 Breakout Board Eagle Design

The breakout board was assembled using the reflow oven in the Engineering Innovation Hub (EIH) at Notre Dame. The assembled breakout board is shown in Figure 7.

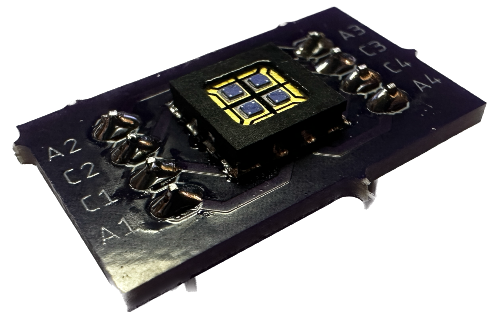

Figure 7. Assembled OPR5925 Breakout Board

IV. Breadboard Assembly

The electrical system was constructed on a breadboard, allowing for simple and flexible construction and modification which were desirable given the short timeline of the project. A schematic of the circuit for the laser guidance system is shown in Figure 8.

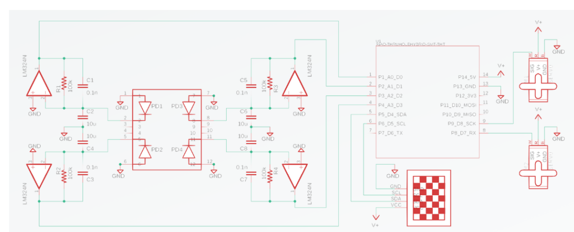

Figure 8. Overall system schematic

While most electronic components were located directly on the breadboard, external connections were made to the servo motors and to a PC via the USB-C port of the XIAO SAMD21. This connection enabled the programming of the system and data transfer for plotting the system’s output on a computer display. A test setup of the breadboard is shown in Figure 9. The final setup was nearly identical, but the quad photodiode was housed in the photodiode assembly rather than on the breadboard.

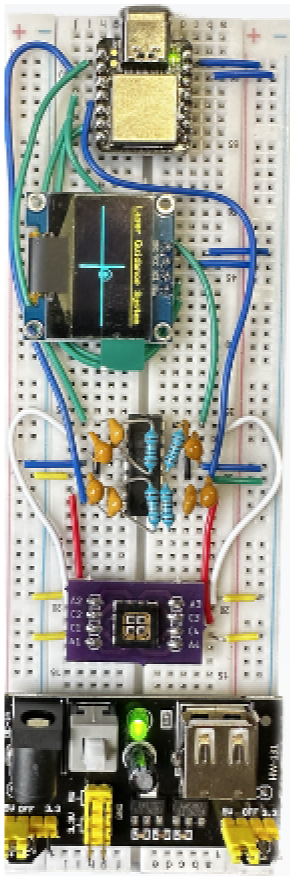

Figure 9. Test breadboard assembly

V. Software

A. XIAO SAMD21 Firmware

The XIAO SAMD21 was programmed in the Arduino IDE to monitor the photodiodes, control the servo motors, print to the OLED screen, and write serial data to the PC. Four files were developed to control the XIAO SAMD221: (1) *Laser_Guidance_Mk_1.ino; (*2) *opr5925.h; (*3) *opr5925.cpp; (*4) *config.h*. *Laser_Guidance_Mk_1.ino* was the main file that included the standard void setup() and void loop() functions. The files *opr5925.h* and *opr5925.cpp* contained the class *opr5925* which included numerous functions to collect and process data from the opr5925. The header file *config.h* contained macro definitions used to configure the signal processing employed by the *opr5925* class.

B. Processing IDE Display

The Processing IDE file, *ProcessingLaserGuidanceGUI.pde*, was created to display the position of the light incident on the OPR5925. The file monitored the incoming serial data from the XIAO SAMD21 and plotted the X and Y coordinates to a display window generated on the PC.

C. Signal Processing

The data from each quadrant of the OPR5925 was processed first by averaging 500 samples. This average was then treated as a single data point and loaded into a cue containing the fifteen previous averages to generate a moving average. The moving averages of each quadrant were then used in conversion to X and Y coordinates. The cues of each quadrant were refreshed after every movement by loading in sixteen new averages of 500 samples.

VI. System Assembly

After assembling the breadboard, the moving components of the system were constructed. The pitch servo motor and OPR5925 were placed in the pitch assembly, while the yaw servo motor was placed in the base assembly. The hemispherical lens was placed on its mount and set about 8 cm from the combined pitch and base assembly. A laptop was connected to the system via the USB-C port of the XIAO SAMD21. A test setup of the system is shown in Figure 10.

Figure 10. Test setup for the laser guidance system

VII. System Performance

Figure 11 shows the position of over 4800 data points recorded over 5 minutes of data collection. The green circle is the target region.

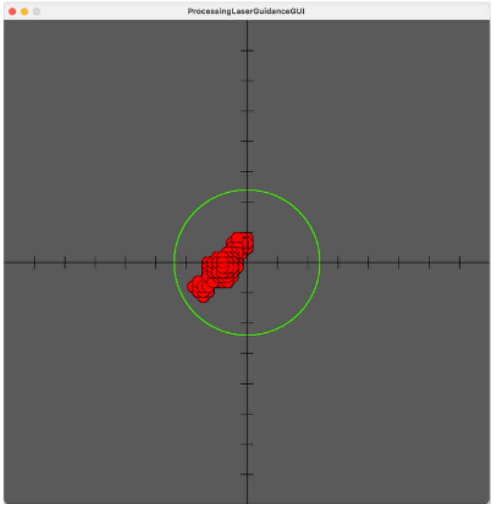

Figure 11. Output display of the laser guidance system on a computer window

The system functioned well, and was capable of orienting itself toward the laser with 1° of precision. The precision of the system was limited by the 1° resolution of the built-in Arduino servo library. Attempts to correct for deviations less than 1° resulted in the system overshooting the target region. This and other potential areas for improvement are discussed in *Section VIII. Improvements and Future Work*.

VIII. Improvements and Future Work

As previously mentioned, improving the system's resolution would greatly improve its performance. Creating an original servo motor class with improved resolution and implementing more sophisticated correction algorithms, such as proportional integral derivative (PID), would provide a movement resolution of less than 1°, improving the sensitivity and precision of the system.

Additionally, utilizing more sophisticated digital signal processing (DSP) methods would increase the speed of the system by enabling the generation of more overall data points with fewer samples averaged per data point. This would allow for higher frequency measurements of the light's position on the quad photodiode.

A third improvement, fixing the hemispherical lens to the photodiode assembly rather than placing it on an external stationary mount, would provide a larger capture area for the laser guidance system. This would allow the system to survey a larger area for the presence of a laser. A larger overall area and increased responsivity at the chosen wavelength may increase the practicality of the laser guidance system. In its current state, the system functions properly when the laser source is oriented directly at the photodiode; however, laser guidance systems for munitions direct the laser at the *target* rather than the detector. In a future design of this system, a more powerful laser source at a frequency near the peak responsivity of the photodiodes may allow the system to detect the reflection of lasers directed at targets and adjust its orientation accordingly.

IX. Conclusion

For this final project, the group set out to design, build, and test a system that not only replicated laser guidance systems implemented in real-world applications but also demonstrated some important optical principles such as responsivity and curved lens interfaces. Despite the limited timeline and budget, the group saw many successes. Instead of purchasing an "all-in-one" quadrant photodiode, the team utilized a combination of off-the-shelf components to implement a quadrant photodiode with acceptable performance at a much lower cost. In addition, the group successfully 3D-printed multiple existing and novel components to create a rotating mount for the quadrant photodiode and breakout board. The group successfully programmed a microcontroller to monitor the photodiodes, control the servo motors, print to the OLED screen, and write serial data to the PC. Overall, the group successfully demonstrated the principles behind laser guidance systems and the value they provide in the present.

References

[1] theGHIZmoEEZYrobotsMore, "EEZYbotARM," Instructables. https://www.instructables.com/EEZYbotARM/