

LASER MULTIPLEX SYSTEM

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Abstract

The main goal of the project is to design a prototype of a projection system that uses two LPT1 laser projectors sponsored by the Boeing Company to display animation of basic geometry shapes. The laser multiplex system will have the accuracy of laser projectors and an improved animation speed. Improved animation speed is achieved by interleaving the frames between the available laser projectors.

To ensure correct synchronization, a calibration system is created to detect whether the two projectors are aligned before the system during initialization period. The result of calibration is sent to a computer through serial communication and results are displayed on the monitor.

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1. Introduction

The laser multiplex system would be used in the production line to enhance the manufacturing process with animation-assisted assembly instructions. This would help with the quality inspections of products and reduce the amount of rework that would travel down the production line otherwise.

The refresh rate of this system is scaled proportionally to the number of laser projectors [1]. An advantage of this system is that it is a low-cost alternative to a high-refresh-rate laser projector.

1.1 Design Overview

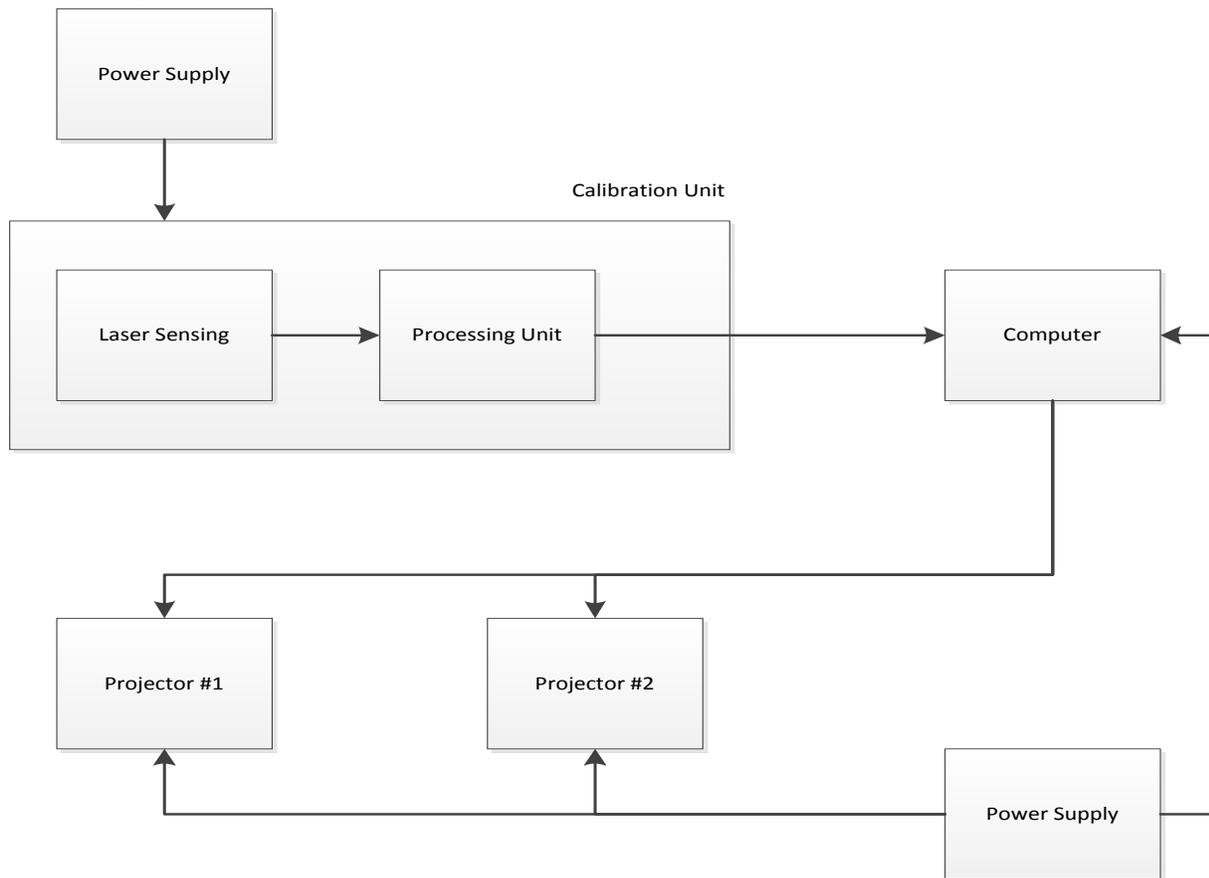


Figure 1 Overall block diagram of the system

The system is divided into two main components, which are the calibration unit and the laser multiplex system. The design processes of these two components are independent from each other.

The calibration unit consists of laser sensing unit, processing unit and a graphical user interface on the computer. During the calibration process, the computer will send commands to the projectors and they will project a test pattern to the sensing circuit on the test board. The main

component of the sensing circuit is a 4x4 photodiodes square matrix. This photodiodes matrix will convert laser lighting to proper voltage signals and send them to the processing unit. The processing unit consists of three microcontrollers those will analyze the voltage signals and send the calibration results to the computer through a serial port, and a graphical user interface will display the results to the user.

As for the laser multiplex system, each of the laser projectors is controlled by an embedded PC through a software called RayTracer. Another computer can remotely send commands to the RayTracer via a TCP connection. Those commands are generated from a JAVA API and the projection patterns are defined in XML files.

2 Design

2.1 Laser Sensing Unit

There are 16 photodiodes (arranged as a 4 x 4 photodiodes square matrix) used together as a sensing plane to detect the laser light.

The photodiodes are connected as shown in Figure 2. Each photodiode is reverse-biased by 5 V so that they are working in photodiode region of I-V curve [2]. And, resistor R2 is used to protect the photodiode by limiting the current flow through the photodiode. The capacitor $C2 = 1\mu F$ is the decoupling capacitor to reduce the effect from the power supply impedance [3].

The circuit is then connected to a high pass filter to reject the DC current induced by natural lighting conditions. The high pass filter is formed by the RC components and it has a low cut-off frequency.

Next, the voltage from R3 is amplified by an op-amp (the left op-amp in Figure 2) with a closed loop DC gain. Afterwards, it is followed by a buffering stage to reduce the loading effect. The right op-amp in Figure 2 is used as a buffer stage between the circuit and the PIC18F4550 of processing unit.

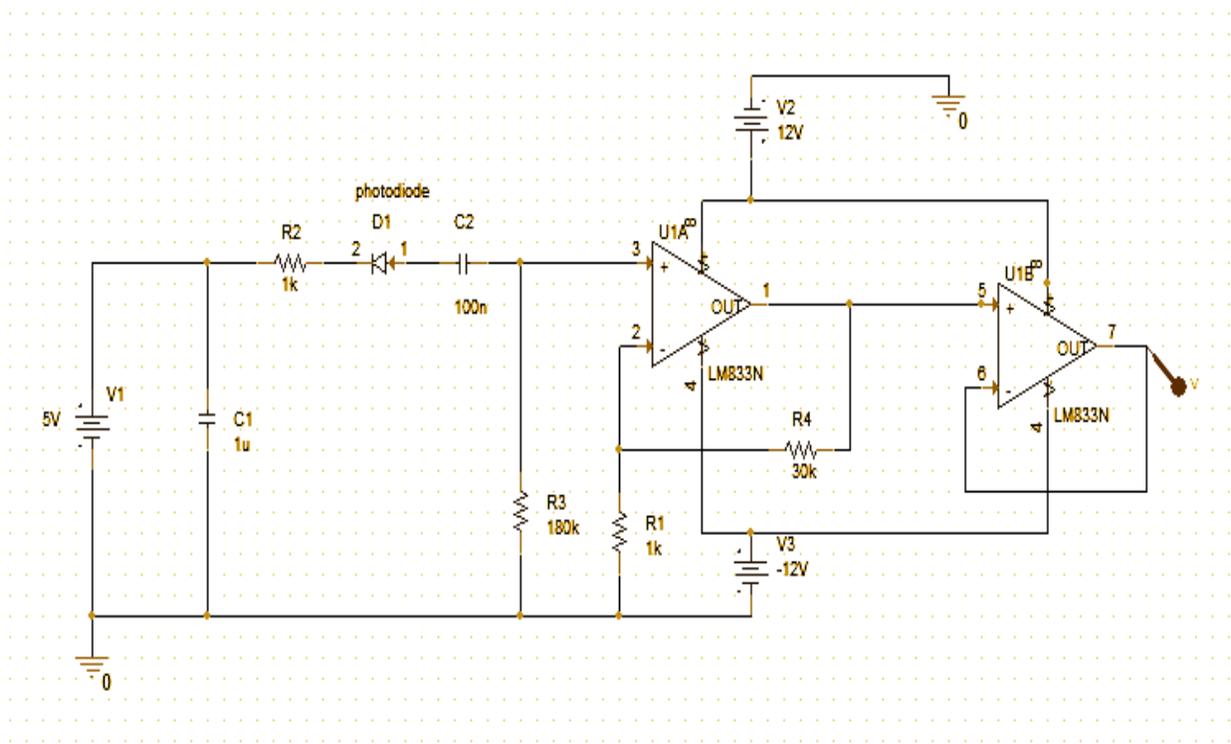


Figure 2 Calibration Circuit

Calculations:

$$R3=180\text{ k}\Omega, C2=100\text{ nF}, R4=30\text{ k}\Omega, R1=1\text{ K}\Omega$$

$$\text{Amplifier DC gain is } \frac{R4}{R1} = 30.$$

The resistance of the VTP1188SH photodiode under laser lighting at a distance of 0.5 inch is measured to be around $R_{\text{photodiode}} = 18\text{ k}\Omega$.

$$\text{Therefore, } R = R3 + R_{\text{photodiode}} = 180\text{ k}\Omega + 18\text{ k}\Omega = 198\text{ k}\Omega$$

$$\text{High pass filter cut-off frequency, } f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 198\text{ k} \times 100\text{ n}} \approx 8.8\text{ Hz}$$

2.2 Processing Unit

The circuit diagram of the processing unit is shown in Appendix A.

The processing unit consists of three PIC18F4550 microcontrollers [4].

One of the microcontrollers (the main microcontroller) will process 13 of the 16 outputs from the laser sensing unit and will send results to the computer in UART data.

Another microcontroller (the secondary microcontroller) will process the remaining 3 outputs from the laser sensing unit and will send results to the main microcontroller via six TTL compatible signals.

The third microcontroller produces a periodic square wave (named as Clk in the program) with a frequency of 0.25 Hz to the main microcontroller and the secondary microcontroller.

For each analog input, the main microcontroller and the secondary microcontroller count the total number of transitions from logic 0 to logic 1 when Clk is high. Therefore, the microcontrollers count the transitions in each analog input for two seconds.

Transitions are counted by the microcontrollers as the lasers trace a pattern at some frequency. By knowing the number of transitions in an analog output from a photodiode, whether the presence of laser light on that photodiode can be determined if the following three conditions are fulfilled:

- a) The two lasers should trace a same pattern
- b) One of the lasers should trace at a frequency which is a multiple of the other laser's frequency
- c) They should start tracing at different starting coordinates

The three conditions are important because the photodiode will be saturated even when there is only one laser shining on it. In order to know the presence of a laser on a photodiode, the two lasers should never be present on that photodiode at the same time.

2.2.1 UART data

The processing unit will send out UART data to communicate with the PC.

Nineteen bytes of data is sent from the main microcontroller when the analysis of signals from laser sensing unit complete. The format is specified as shown in the following table.

Table 1 Format of 19 bytes data sent from main microcontroller to PC

| Start Byte | 16 Color Bytes | Status Byte | Stop Byte |
|------------|--|--------------|-----------|
| 0xff | -higher four bits represent the number of photodiodes -lower four bits represent laser presence on this diode | 0x00 or 0x11 | 0xff |

Table 2 Possible cases on a photodiode and its corresponding bits sent in UART data

| Case | Description | Bits | Color in GUI |
|------|---|------|--------------|
| 1 | No laser traced through this photodiode | 0001 | Grey |
| 2 | Both lasers traced through this photodiode | 0010 | Green |
| 3 | Only Laser 2 traced through this photodiode | 0100 | Blue |
| 4 | Only Laser 1 traced through this photodiode | 1000 | Red |

2.2.2 Communication with PC

MAX232 is used to convert UART data such that the data can be read by a standard RS232-port. Figure 3 shows the connection of MAX232, UART data from main microcontroller and RS-232 data from PC.

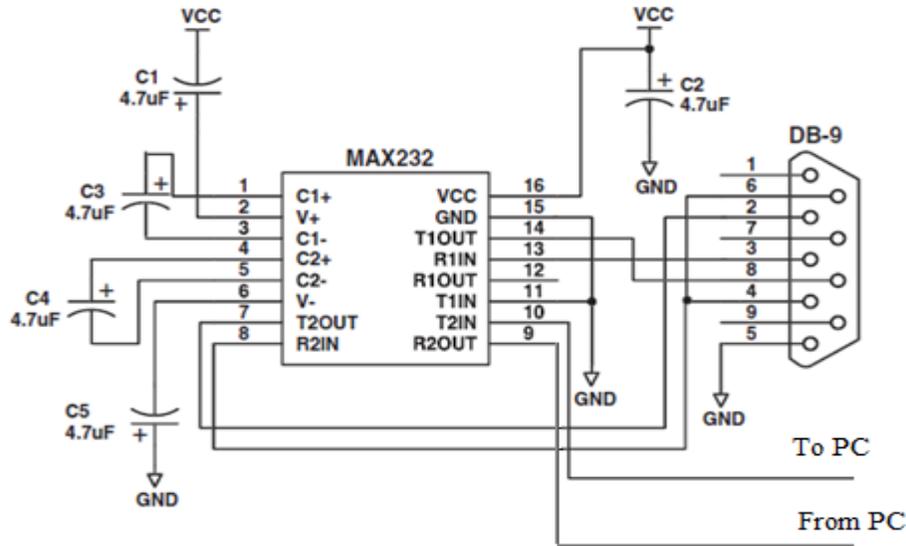


Figure 3 MAX232 connection diagram

2.2 Graphical User Interface

The Graphical interface is Windows software that is used to graphically display the lighting condition of photodiodes matrix to reflect the real results obtained from the test board. The graphical user interface is designed using a cross-platform application framework called Qt [5]. The code is written in C++. Additionally, the Serial Port control class is downloaded from the internet [6].

The design consists of four steps:

- a) Data Import
- b) Graphical Layout
- c) Case identification
- d) Interact functionality

Figure 4 and Figure 5 illustrate two of the test cases on how the two projectors are aligned.

In the program, each circle represents a photodiode on the real test board. The expected pattern is the four photodiodes in the middle. In a perfect alignment case, both projectors should shine laser only to these four photodiodes and the circle at the top right corner will display a check mark. Note that this application is designed for separate calibrations. The check mark will be displayed as long as one of the projectors is aligned correctly. The reason is explained in more details in the section 5.2.

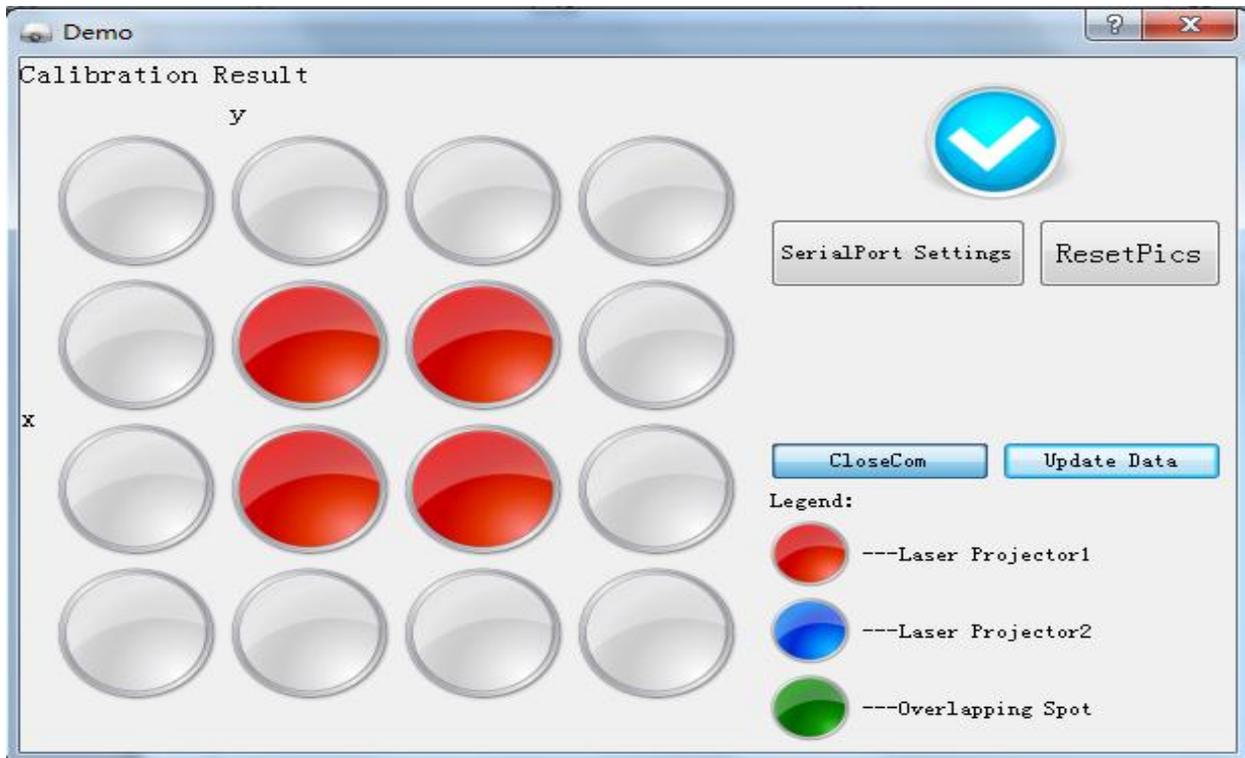


Figure 4 Laser Projector 1 is aligned correctly

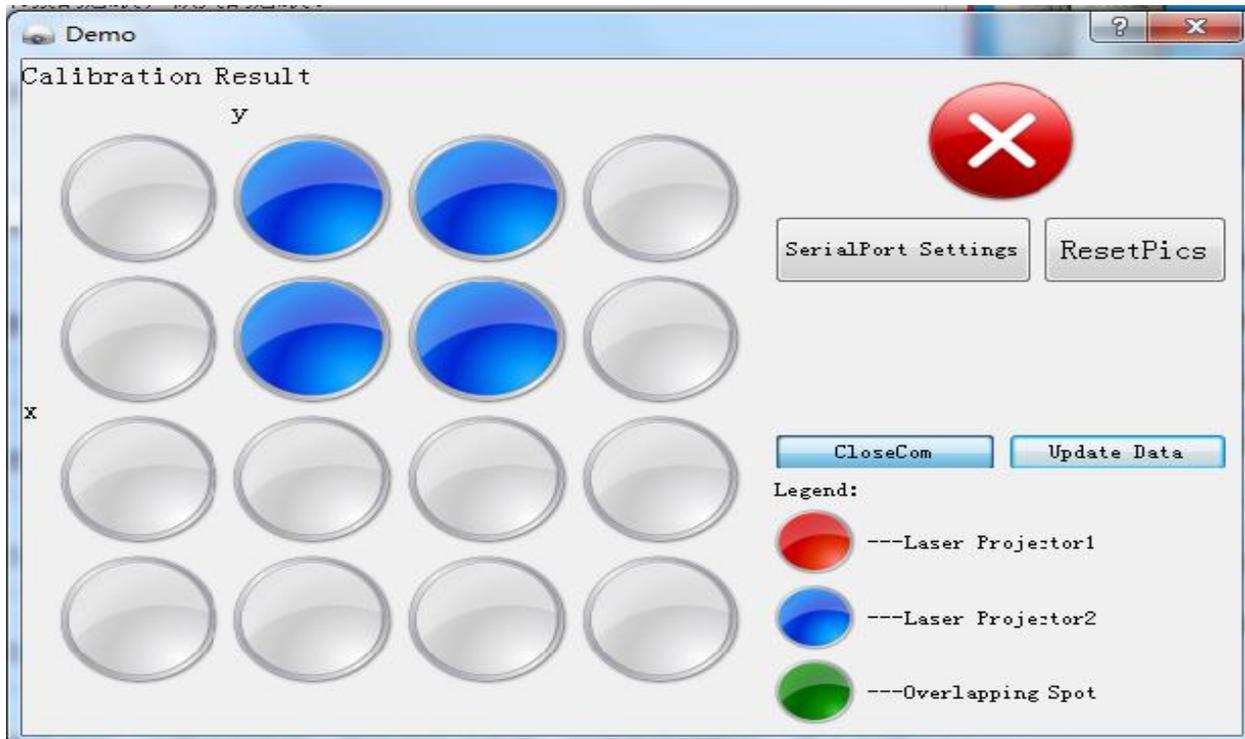


Figure 5 Laser Projector 2 is not aligned correctly

2.3 Remote RayTracer API

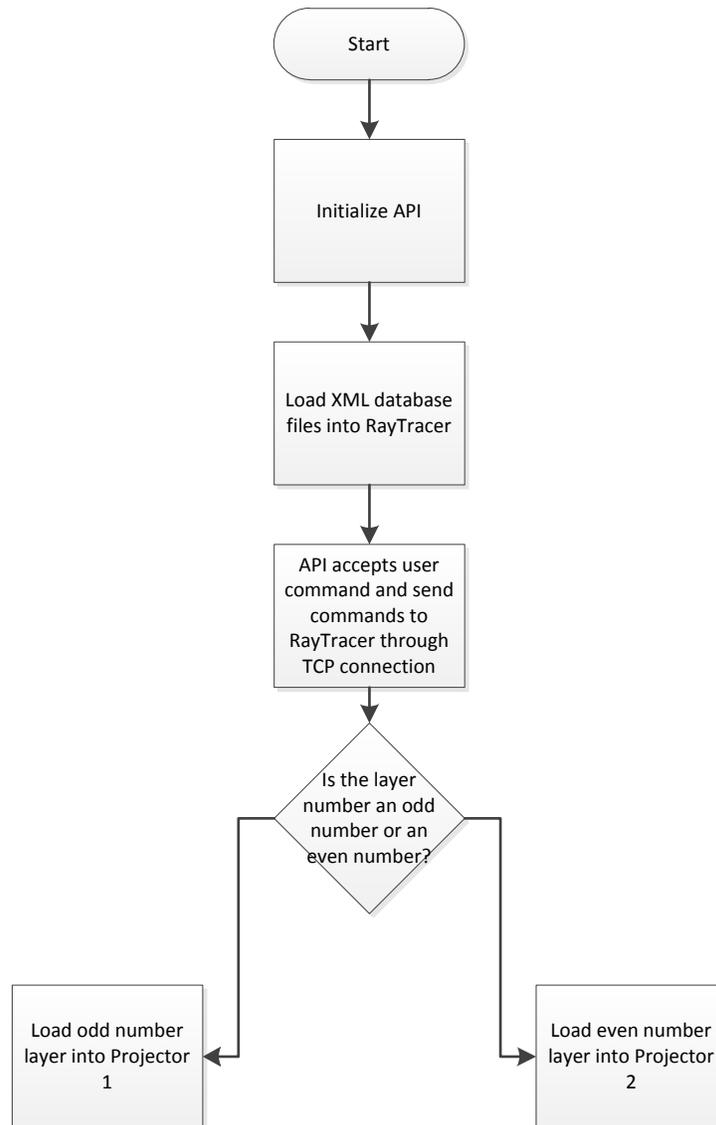


Figure 6 API Flowchart for Interleaving Frames between Laser Projectors

API, a user interface that indirectly controls the embedded PC within the laser projectors, controls the laser movements of the laser projectors. API will send corresponding commands to the RayTracer, a graphical interface that is within the embedded PC in the laser projectors. Therefore, the laser projectors can be controlled from the computer.

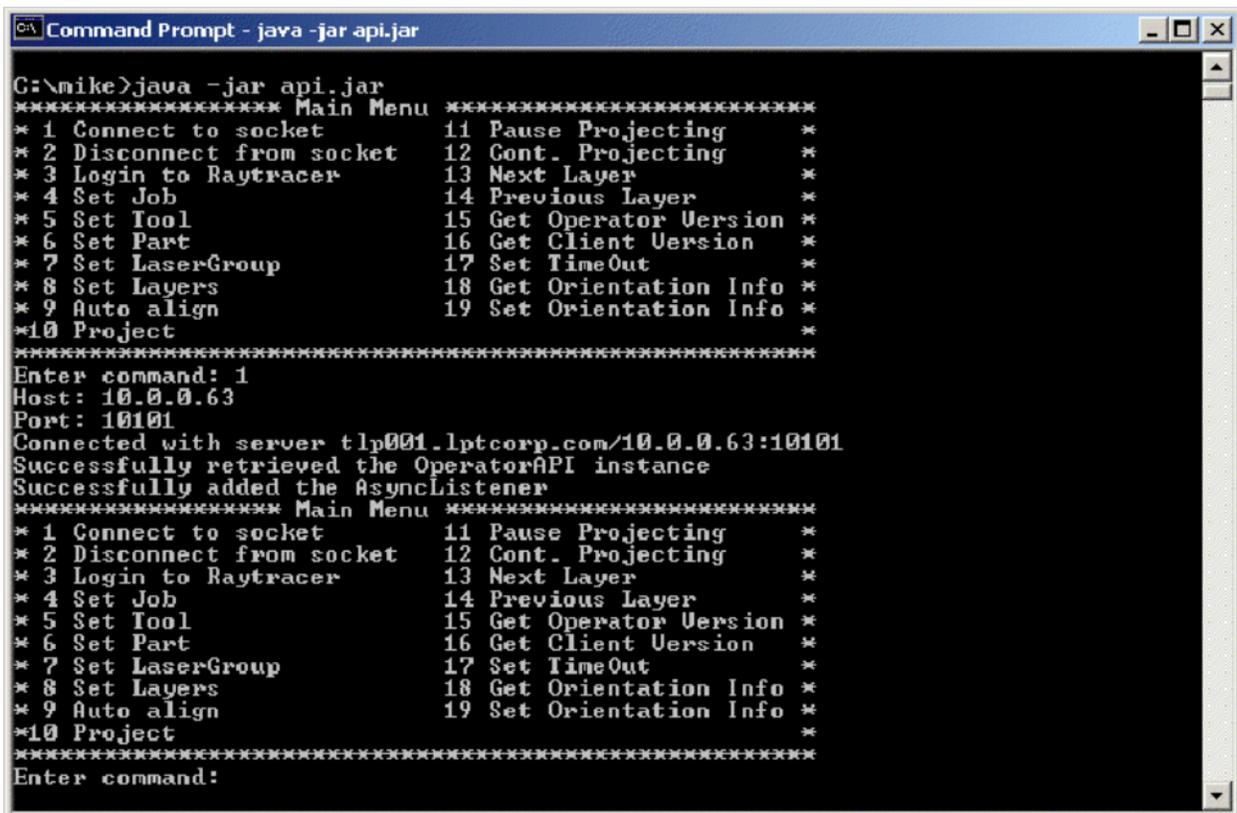
RayTracer reads in projection file that describes the curves that are to be projected in 3D coordinates. The curves are defined in coordinates and assigned as “Layers”. Layers are part of the hierarchical software abstraction. The laser projector measures the angular location of key points on the target, and from these measurements, it solves for the location of the target relative to the projector.

When users select layers to be projected, RayTracer calculates the transformation of the curves to projection angles. And, the sequence of command is sent to the galvanometer, which turns the beam steering mirrors. These mirrors move the point laser source over the target and the laser is switched on and off at appropriate times to trace the curves on the target.

To achieve animation speed better than just a single projector, layers are split and interleave between the two projectors. Then, each projector is only responsible for half of the total layers. Animation speed is doubled.

The Remote RayTracer API contains a class named OperatorAPI. It is an abstraction layer to the low level string commands and socket interaction to implement for the documented behavior in RayTracer Remote API Manual Rev. 2 (also uploaded on ECE 445 website through PACE) .

By adding methods to the APITest class, complex behavior can be created as menu choices by making several sequential calls to OperatorAPI. For example, an “animation” method allows users to specify the total number of layers in an animation and the number of repetitions. The “animation” will then call the "SetLayers" method in each cycle and then call the "Project" method to project.



```
Command Prompt - java -jar api.jar
G:\mike>java -jar api.jar
***** Main Menu *****
* 1 Connect to socket          11 Pause Projecting      *
* 2 Disconnect from socket    12 Cont. Projecting    *
* 3 Login to Raytracer        13 Next Layer          *
* 4 Set Job                   14 Previous Layer     *
* 5 Set Tool                  15 Get Operator Version*
* 6 Set Part                  16 Get Client Version *
* 7 Set LaserGroup           17 Set TimeOut        *
* 8 Set Layers                18 Get Orientation Info*
* 9 Auto align                19 Set Orientation Info*
*10 Project                   *
*****
Enter command: 1
Host: 10.0.0.63
Port: 10101
Connected with server tlp001.lptcorp.com/10.0.0.63:10101
Successfully retrieved the OperatorAPI instance
Successfully added the AsyncListener
***** Main Menu *****
* 1 Connect to socket          11 Pause Projecting      *
* 2 Disconnect from socket    12 Cont. Projecting    *
* 3 Login to Raytracer        13 Next Layer          *
* 4 Set Job                   14 Previous Layer     *
* 5 Set Tool                  15 Get Operator Version*
* 6 Set Part                  16 Get Client Version *
* 7 Set LaserGroup           17 Set TimeOut        *
* 8 Set Layers                18 Get Orientation Info*
* 9 Auto align                19 Set Orientation Info*
*10 Project                   *
*****
Enter command:
```

Figure 7 Remote RayTracer API

3. Design Verification

- a. The current detected when a photodiode is ON is 20.5 μA , which insures the photodiode is good to work.
- b. The Figure 8 below is waveform of voltage across the resister R3 when laser light shines on the photodiode under natural light conditions, which shows the step response of the photodiode.

The time period is 1s and from the graph it shows when laser shining on the photodiode at 0.7s, the voltage jumps up to 0.65V in a very short time. Because the two frequencies of the two laser lights will be used are 10Hz and 15Hz, the response time should less than both 0.1s and $\frac{1}{15} \text{ s}$. And the response time from the graph is about 0.01s, which satisfies the frequency requirement.

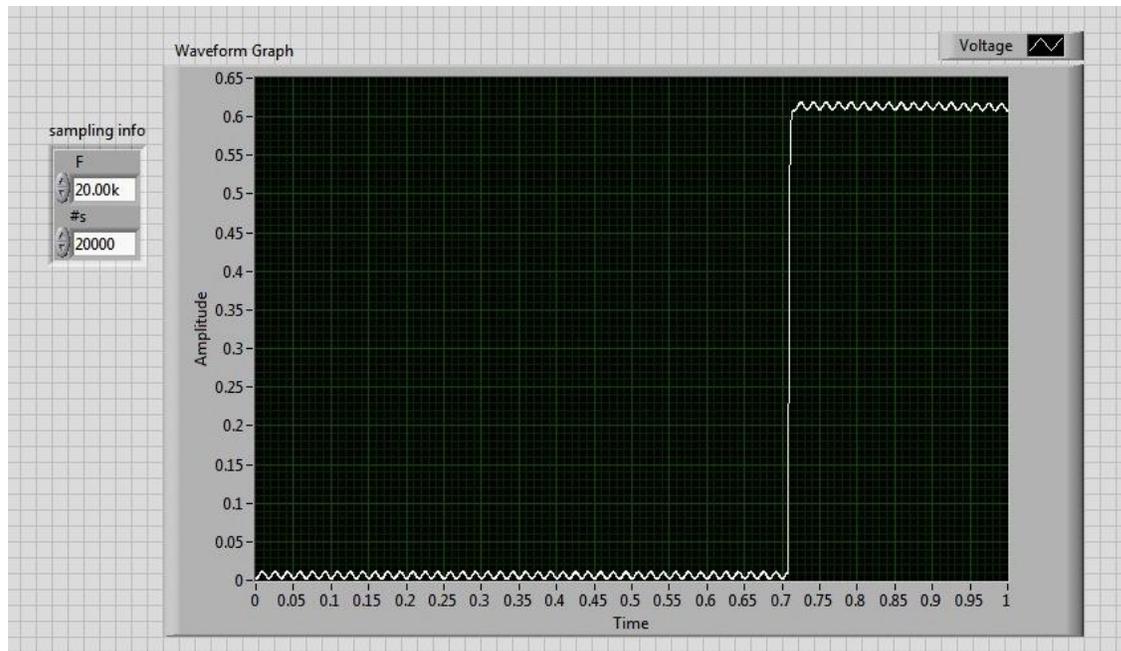


Figure 8 Step response of photodiode

- c. Figure 9 shows the waveform of voltage across the resister R2 when two laser lights shine on the photodiode. The voltage pulse is about 0.6V, almost the same as only one laser shining on the photodiode. The result shows that the power of one laser is enough to make the current saturated.

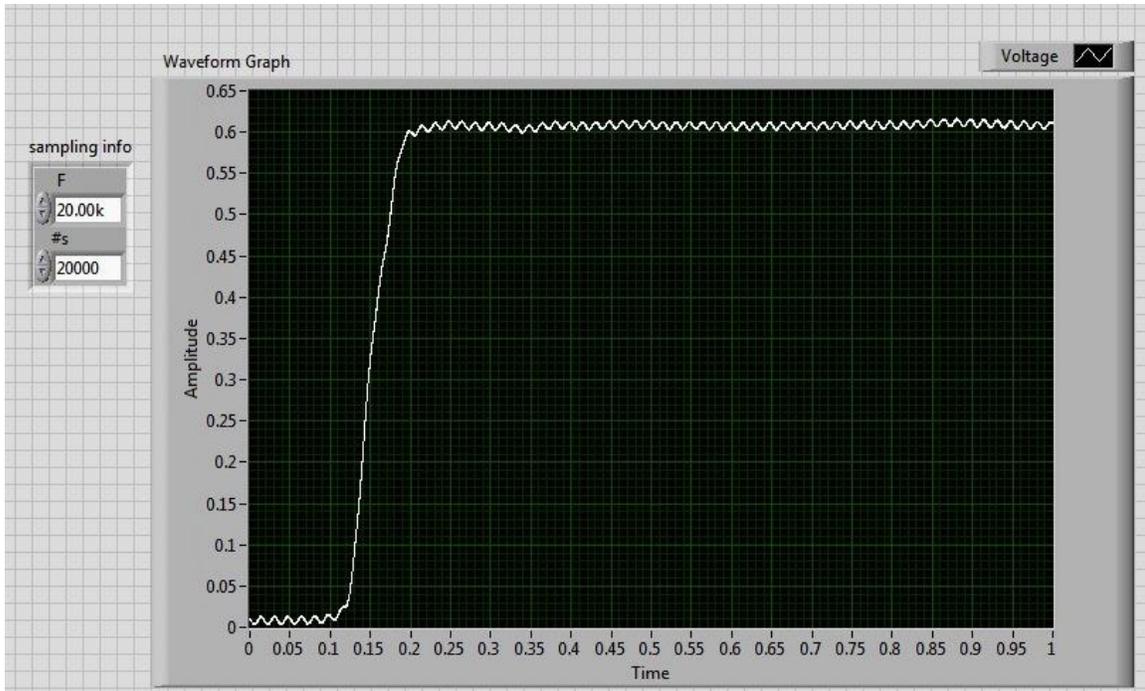


Figure 9 voltage response when two laser lights shine on the photodiode

- d. Figure 10 shows the waveform of voltage across the resistor R3 when only natural light shines on the photodiode. The voltage pulse is only about 0.01V and it is less than 0.05V, from which it indicates the DC block works properly to reject the natural light induced current.

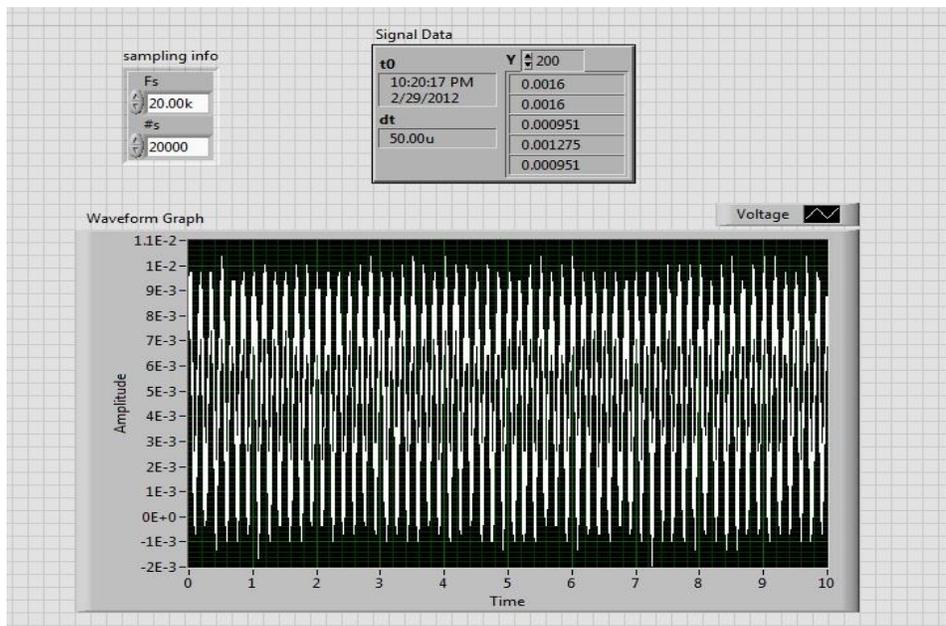


Figure 10 natural light condition with DC block

- e. Figure 11 below is the output voltage of the sensing circuit when laser shining on the photodiode. The peak voltage $V_{out} = 3.563V$ indicates the outputs of laser sensing circuit are neat and microcontrollers can count the transitions with relatively small error.

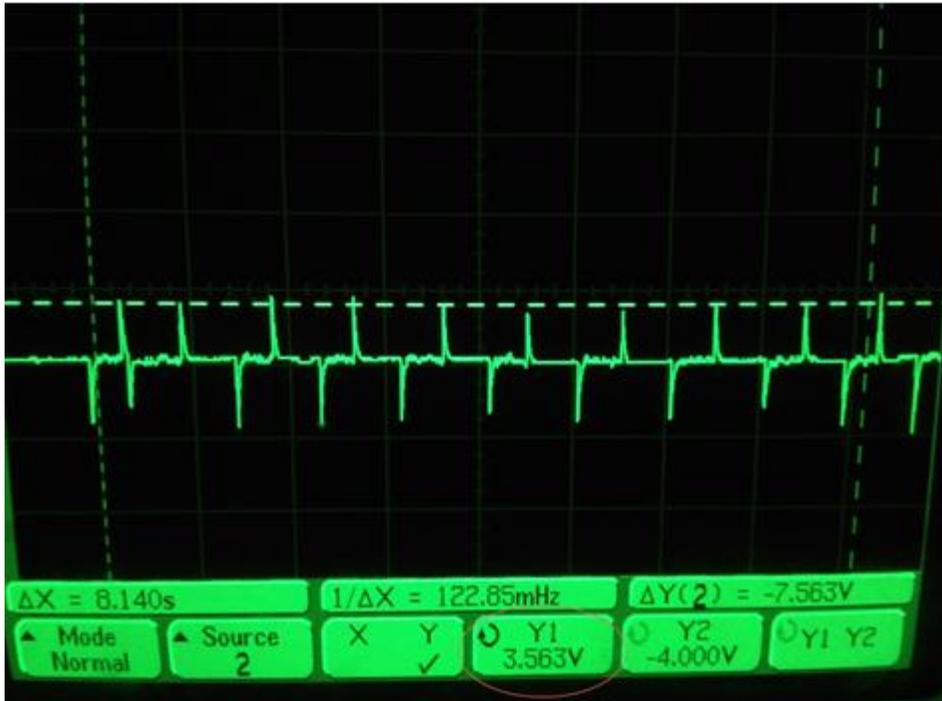


Figure 11 Voltage output of the sensing circuit when laser shining on

- f. Since the photodiodes are arranged close to each other, there will be light reflection between nearby photodiodes. When shining on one photodiode, the peak voltage output on the photodiode that is located beside is $V_{effect} = 2.5V$. In order to reduce this effect, a cross-section board is made to put in between the photodiodes. From Figure 12 below, it shows the effect voltage output after applying the board is $V_{new-effect} = 0.41V$.



Figure 12 reflection effect voltage output with cross-section board on

- g. Figure 13 below is the Matlab simulation graph of the circuit frequency, from where we can read that the steady frequency is about 7.8Hz . The frequency response indicates that the values of components selected for the circuit are good and the circuit is working as intended.

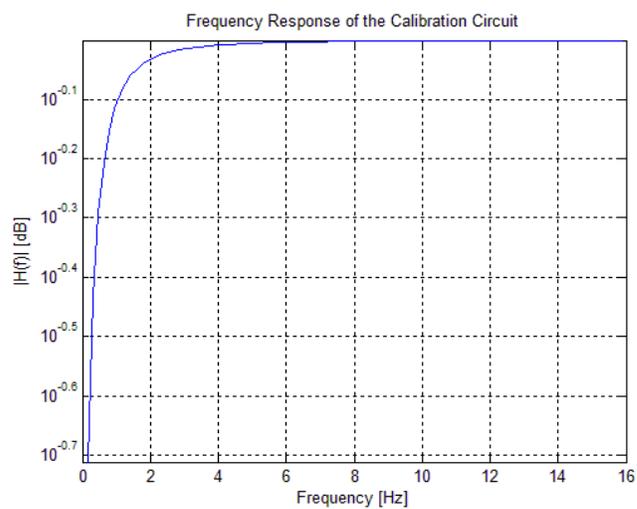


Figure 13 Frequency response of calibration circuit

4. Costs

4.1 Parts

Table 3 Parts Cost

| Part # | Mft | Desc | Unit Price | Quantity | Total |
|------------------|-------------------|-------------------------------------|------------|----------|------------|
| VTP1188SH | EG&G | Silicon Photodiode | \$2.0 | 16 | \$32 |
| LPT1 | LPT | Laser Projector | \$25000 | 2 | \$50000 |
| PIC18F4550 | MICROCHIP | Microcontroller | \$4.47 | 3 | \$13.41 |
| LM833N | ANALOG DEVICES | Amplifier | \$0.46 | 16 | \$7.36 |
| 81-EA1X3A100JCIB | XICON | 10PF Capacitor | \$0.15 | 16 | \$2.4 |
| LabView 2011 | NI | Labview Student Edition Software | \$60 | 1 | \$60 |
| Grand Total | | | | | \$50115.17 |

4.2 Labor

Table 4 Labor Cost

| Name | 2.5*rate*hours | Total |
|-------------------|----------------|---------|
| Wei Keong Eiew | 2.5*\$20*100 | \$5000 |
| Lei Jin | 2.5*\$20*100 | \$5000 |
| Nan Wang | 2.5*\$20*100 | \$5000 |
| Grand Total | | \$15000 |

4.3 Grand Total

$$\begin{aligned} \text{Total cost} &= \text{Parts Cost Total} + \text{Labor Cost Total} \\ &= \$65115.17 \end{aligned}$$

5. Conclusion

5.1 Accomplishments

In this project, a calibration unit that helps align two laser projectors is built. It detects misalignment within an area of 2.56 inch². The information is displayed through a GUI.

A single laser projector can be controlled by a PC using a JAVA API to project 2D animations.

5.2 Uncertainties

In an ideal situation where the two laser projectors have deterministic refresh rate, simultaneous calibration is achievable. However, it is difficult to precisely control the refresh rate of laser projectors, and each laser projector does not exhibit identical refresh rate even for the same projection. In this case, one of the projectors has significantly larger refresh rate than the other. For a typical square projection pattern, the one with larger refresh rate can cause 250 to 350 transitions. In contrast, the slower model can only cause 10 to 20 transitions per second. The enormous discrepancy makes it impossible to calibrate two laser projectors simultaneously. Therefore, they can only be calibrated separately.

Since the RayTracers have different speed of loading frames and the projectors have not only different but also inconsistent refresh rate, the resulting animation is not always consistent.

5.3 Ethical considerations

It is crucial for engineers to make sure their works are safe and trusted by people. Therefore, we must adhere and conduct according to an ethical standards.

Agreement #5 of IEEE Code of Ethics, which states “to improve the understanding of technology, its appropriate application, and potential consequences [7],” is especially related to us in this project. Our project is mainly about dealing with the issue of slow laser animation. We are to design a proof of concept to show that higher animation speed is possible by using multiple projectors working in concert. By studying the possibility of faster laser animation, it helps to deepen our understanding of lasers and this could be a new technology that would benefit many in the future.

Agreement #6 of IEEE Codes of Ethics, which states “to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations[7].” In this project we are working for the Boeing Company to help them improve certain technology. We should let them know our expertise as well as limitations. And we should only take on tasks that we are capable of doing or take on them after training.

Furthermore, we would conduct as appropriate as it is highlighted by IEEE Code of Ethics. We would “seek, accept and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contribution of others.” We would also “avoid injuring others,

their property, reputation, or employment by false or malicious action.” Moreover, we would “assist colleagues and co-workers in their professional development and support them in following the code of ethics [7].”

5.4 Future work

The better design for the animation control from the JAVA API is to define another abstraction layer for an animation object. This abstraction layer can figure out what the data and methods need to be used or called, and encapsulate an instance of OperatorAPI within it. Then, calling the methods of the Animation object will create a simple straight-forward interface to animation.

References

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Appendix B Requirement and Verification Table

| Requirement | Verification | Verified? |
|--|--|-------------------------------------|
| Power Supply | | |
| <p>1. Power supply</p> <p>The power supply must provide a stable +5 V DC, +12 V DC and -12 V DC.</p> | <p>The power supply must supply appropriate voltage to other units.</p> <p>a. The voltages across the power supply are measured using DDM, the output should be stable at 50.5, 120.5 V and -120.5 V.</p> | √ |
| Calibration Circuit | | |
| <p>2. The photodiodes will correctly sense the light from lasers and send analog signal to the microcontrollers.</p> <p>3. The PIC will process the data and send the alignment information to the computer user interface through the communication link.</p> <p>a. The high pass filter can block direct current from natural light and produce a stable constant voltage.</p> <p>b. When laser is shining on the photodiode at a frequency higher than the cut-off frequency, the output of the photodiode circuit must have a magnitude of at least 3V.</p> <p>c. When the cross board is applied, the effect on voltage output should be reduced.</p> <p>d. The microcontroller must correctly calculate the transitions from the analog input of photodiode circuit.</p> | <p>The calibration unit can tell if the projectors are aligned correctly.</p> <p>a. Measure the output of the photodiode circuit under natural lighting condition with oscilloscope and see if it is a stable constant voltage that below 2.5V, if so, DC signals are mostly blocked.</p> <p>b. Measure the voltage output when laser is tracing with oscilloscope and see if the output has a magnitude greater than 3V.</p> <p>c. Measure the voltage output of photodiode 1 when laser is shining on photodiode 2 next to it. The voltage output from photodiode 1 should not be affected.</p> <p>d. Connect square wave signal to the microcontroller and program the microcontroller to output the transitions contained in each signal in UART serial data output.</p> | <p>√</p> <p>√</p> <p>√</p> <p>√</p> |

| Communication Link | | |
|---|--|-------------------|
| <p>4. Communication link must convert UART data to data that can be read by a serial port.</p> <p>a. MAX232 converts the UART data correctly so that it can be read by a standard RS-232 COM port.</p> | <p>The computer should receive the intended data of the calibration module with the help of MAX232.</p> <p>a. UART output of microcontroller is checked using Serial Port Test Software.</p> | √ |
| Laser Projectors | | |
| <p>5. The whole laser multiplex system should project the animation faster than a single laser projector.</p> <p>a. Can achieve about twice the refresh rate of a single laser projector</p> | <p>The multiple projectors should improve the animation speed.</p> <p>a. One of the projectors will play the animation. Next, the refresh rate of same animation using laser multiplex is determined and compared to the refresh rate of a single projector. The speed should be doubled.</p> | × |
| Calibration Graphical Interface | | |
| <p>6. This interface should inform users how the lasers tracing on the calibration board.</p> <p>a. Display traces of laser using three colors</p> <p>b. Display the real alignment and/or the error that causes the misalignment</p> | <p>The interface should show whether the two projectors are aligned correctly or not. And how the real projection patterns compare with the expected pattern.</p> <p>a. The expected pattern is the center square. One of the projections will be in red and the other one will be in blue. An overlapping spot will be marked in green.</p> <p>b. If two projectors aligned correctly, the center four circles will be painted in green. In addition, a check mark will be shown. Otherwise, an error mark is shown. And the interface will show the user the misalignment.</p> | <p>√</p> <p>√</p> |