Automated Optical Setup

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***Abstract* — The AOS is a system designed to help CREOL increase their efficiency when performing Optical Parametric Oscillator (OPO) experiments. The AOS includes three subsystems. The first subsystem is the adjustable gain amplifier, who's primary role is to increase the signal strength from the light sensor. The second subsystem will include a microcontroller responsible for the Liquid Crystal Display (LCD), Analog/Digital conversion, as well as establishing communication with the computer. The third subsystem will be responsible for the interaction of the computer and the crystal mount's controller to change its orientation through the LabVIEW environment.**

***Index Terms* — Analog circuits, Electronic circuits, Microcontrollers, MOSFET circuits, Operational amplifiers, Analog-digital conversion.**

I. Introduction

This project was proposed in order to make Optical Parametric Oscillator (OPO) easier by automating much of the processes. Traditionally mounts for stabilizing mirrors and a crystal had to be adjusted by hand. We hope that by connecting the motors on the mount to a computer to control them, and by having sensors setup to tell the computer which motor to move what distance and in which direction, will provide a great benefit. Not only will this allow for a reduced time orienting the mounts, but it will also allow for corrections in the orientation to be constantly updated while the OPO is running. Furthermore, a computer can make much more refined with a much higher degree of accuracy than a human turning a knob by hand. Therefore our main objectives consist of making OPO experiments more automated and allowing corrections to be made mid-experiment. We also plan on amplifying the signal of our light sensor that measures the intensity of the laser beam after it passes through the crystal and allowing the user to manually adjust the mounts.

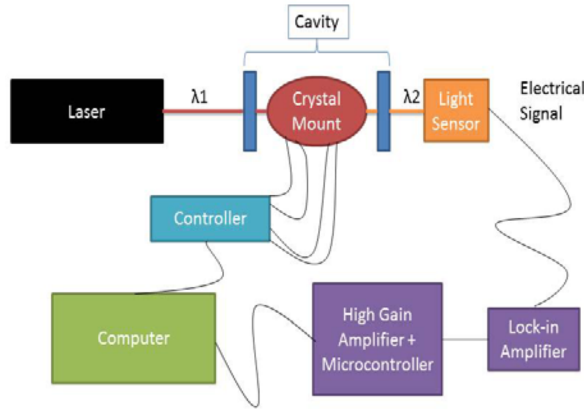

Fig. 1. The AOS system integrating with the OPO.

II. Specifications

There are several specifications our system needed to meet in order to interact and support the OPO experiments performed at CREOL. The hardware and software requirements can be found below.

GUI:

1. User interface application update time is less than 2s.

Display:

2. LCD display dimensions of less than 25 mm by 60mm.
3. LCD supports display of at least 10 characters.

Mount:

4. Mount supports position accuracy of 0.1°
5. Mount's adjustment sensitivity of at least 2 micro-radians.
6. Mount speed is at least .5 degree/sec.
7. Mount's angular range of ±2°.
8. Mount's thickness is less than 35mm.

Amplifier:

9. Adjustable again of 6x increments, maximum of 46656 gain.
10. Supports RF signal up to 15 kHz, while filtering out noises outside of the signal's band.

III. System Components

A. Microcontroller

The microcontroller used in the design will be the Atmega328. The Atmega328 offers a much higher frequency of oscillation; 20MHz more than the LM3S8962. The Atmega328 is also much easier to work with because of its available 32 pin DIP packaging. This microcontroller also features a 10 bit A/D converter from 6 channels and an ADC Noise Reduction Mode that will turn off the CPU when the SLEEP instruction is given to minimize noise and take higher resolution measurements. Once the conversion is done, a signal is sent to the CPU to turn back on. While the LM3S8962 and the Atmega328 have more or less the same features, the Atmega seems to be more popular and much easier to work with. It is open source, making it very easy to obtain schematics and code examples for it. It's simple design would make debugging much faster than working with 100 pins.

B. Liquid Crystal Display (LCD)

The LCD unit used in the design will be the NHD-0208AZ-FL-YBW from Newhaven Display. The Fig. 2 is reprinted with permission from Newhaven Display International. This figure shows how the digital output pins from a microcontroller should be interfaced a few of the pins to the LCD board in order to write characters to the display. Characters are written to their location in RAM using an address given in the datasheet followed by the character that you wish for. This display is simple because it also includes commands to clear out the whole display or turn it off. This display module was chosen over many 7 segment displays because we wanted more freedom with what was being displayed in case we decided to include other information. With the included backlighting, it is perfect for the darkness associated with optical labs. This is also one of the few displays that includes a built in character map because of the integrated driver built into this unit. The price difference between purchasing an integrated display such as this and designing your own is negligible if not better.

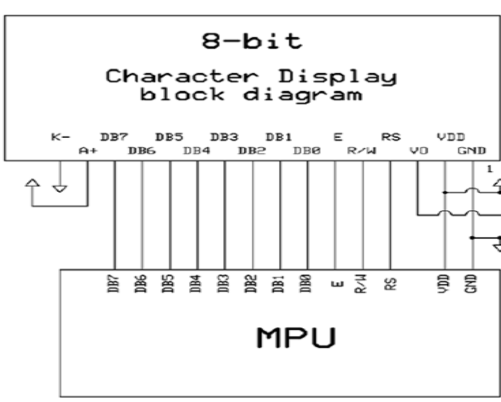

Fig. 2. Reprinted with permission from New Haven Display, typical connection with a microcontroller used to help design schematic.

C. Motorized Optical Mount

A motorized optical mount is needed to adjust the crystal's orientation for the project. The AG-M100L from Newport was chosen as the mount. Below in Fig. 3 is a diagram of a general motorized mirror mount that will be required for our project. The circumference in the middle will be used to hold cylindrical fastener for a cubed shaped optical elements. Different mounts have difference circumference designed to hold various mirror size. It is desirable that the circumference for our motorized mirror mount will be 1 inch in radius.

From the diagram, there are two motors located at the bottom right corner and the upper left corner. From the majority of motorized mirror mounts, these motors can be varied between the step motor and the squiggle motor. The motors are used to adjust the mirror’s orientation. Instead of manually turning the screw at the pivot point, the motors will turn the screw instead. Because the motors are responsible for the adjustments, it is very important in determining many aspects of the motorized mirror mount.

The first aspect would be the accuracy and precision the motorized mirror mount can be. As there are more steps in each revolution, the more accurate the motorized mirror mount can become. In addition to being accurate, the motor also is important in determining the speed at which the mirror moves and changes its orientation. This is usually measured using degrees per second.

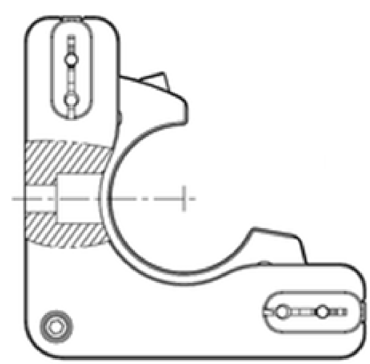

Fig. 3. Front view of the motorized piezo mount.

IV. SUBSYSTEMS

There is a total of four subsystems in the AOS project.

A. Light Sensor to Amplification System

This subsystem will be responsible for amplifying the weak signal from the sensor to a strong enough signal that can be sampled correctly by another subsystem. With the help of NMOSFETs, the amplifier has the ability to provide the user with an ability to choose various gains that are multiples of 6. The maximum gain will be 46656 or 6^6. The amplifier will also provide the ability for the signal to bypass the amplifier if amplification is not needed. The amplifier will be able to filter noises outside of the expected signal's frequency band.

B. Amplifier with Microcontroller Subsystem

This subsystem is responsible for converting the amplified signal from analog to digital. The signal will be past to a 24-bits analog to digital converter. In addition, this subsystem will be primarily responsible for adjusting the gain of the amplifier. Due to the lack of pins on the microcontroller, the PCF8574 was used to increase the I/O pins which are needed to control 6 N-channel MOSFETs on the amplifier.

C. Microcontroller with Computer Subsystem

The microcontroller and computer are responsible for controlling everything. Specifically the microcontroller sets the number of op amps to use, gathers data from the amplifier, converts it, and sends that data to the computer. The computer sends a single byte at the beginning to let the microcontroller know how many op amps to turn on so that everything can be controlled from the LabVIEW code. The computer also displays the intensity reading from the amplifier, collects position data of the motors from the motor controller, and sends commands to the motors on how they should move.

D. Computer with Motor Controller Subsystem.

The motor controller is responsible for taking the commands from the computer and translating to what the motors understand. This way programming becomes much easier and faster and the motor controller we chose even has its own LabVIEW library. This library allows us to connect reference lines together to specify the order the commands should be executed. We can also cascade all the error lines together and display them at the end. This also allows several devices to run together in the same program, in case this project ever wanted to be expanded.

V. HARDWARE

A. USB to UART IC

To provide power for our microcontroller and other devices in our system, we will be using the power coming from the USB port of the computer. The schematic for our USB connection can be found in Fig. 4 below. The FT232R was chosen as the choice IC to convert the USB computer interface to the UART interface for the Atmega328. This support IC was selected because of its ease of use due to how much is already integrated onto the chip: the EEPROM, the clock circuit and USB resistors. This IC requires very little support circuitry, and along with its SMT package, will take up very little room on a PCB. The capacitors are for noise reduction and the Ferrite bead is in series to remove EMI noise coming from the FT232R to the computer. This diagram already shows how the Atmega328 can get power from the USB port on the computer, however our circuit will be slightly different to include a low pass filter before reaching the Atmeg328.

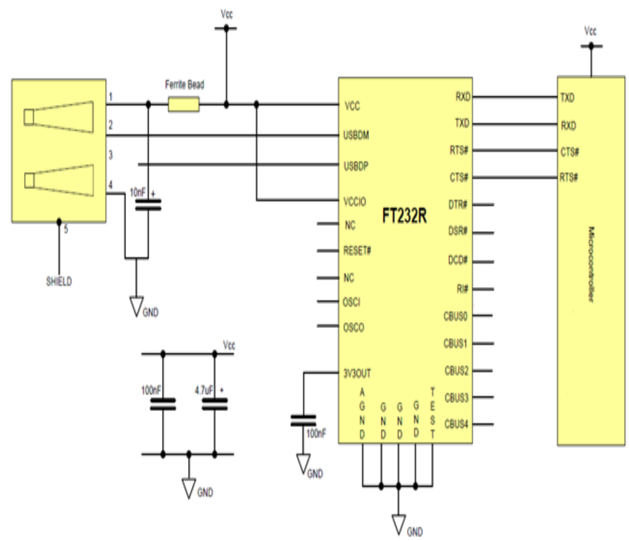

Fig. 4. Reprinted with permission from FTDChip showing the typical connections to a FT232R chip when connected with a Microcontroller.

B. LEDs

There will be two LEDs connected to the FT232R at the CBUS0 and CBUS1 pins in order to visually see communication with the computer and Atmega328. Because these two LEDs will be lighting up a lot, it would be preferred that they are of low light output because the primary area where this will be used is in a dark room with little to no light. Therefore a LED of bright white light would be irritating and painful. For the sake of the user, two low light LEDs will be selected for this application. The first will be a red LED to signal when transmission is occurring. This red LED was also selected because of its low light output, 2.5 milliCandela, low current consumption, and low forward voltage required.

Our other LED is green and will have a 2.2V forward voltage, and a rating of 12 milliCandela that will be dialed down with a voltage divider to lower its brightness. There will be another LED that will be used as an indicator that the microcontroller is on. As it will be on for the time whole time the device is active, it is plain that a low wavelength should be used. A red LED was selected since this will also warn the user that the microcontroller is currently powered. Its forward voltage will be 2v and have a rating of 45 milliCandela that can be restricted if the higher light output is deemed too bright in low light. This LED may also be used as an indication of a reset.

C. Amplifier

The amplifier is crucial for this project because it will be used to amplify the weak RF signal produced by the MCT Detector. The amplifier will be designed to achieve a very high gain of about 6^6. To achieve this gain, several amplifier configurations can be used. The two most popular configuration are the inverting operational amplifier and the non-inverting operational. After consideration, it was decided that the non-inverting operational amplifier configuration will be used due to the ease of parts acquisition. One possible design architectures can be to have various non-inverting operational amplifiers to be connected in cascade. The block diagram in Figure Fig. 5 describes the general layout of the connection. The Amplifier system will consists of six non-inverting operational amplifiers with a gain of six. When it is connected in series, the gain will be multiplied each time as the signal passes through the operational amplifier. With this configuration, we will achieve our desired gain of 6^6.

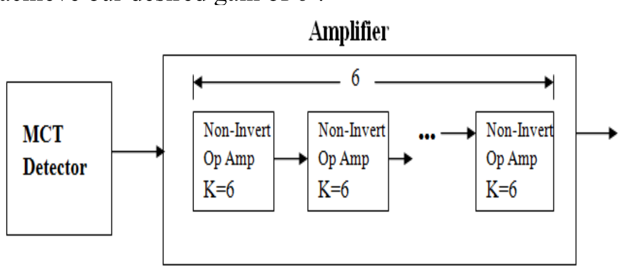

Fig. 5. Initial block diagram of the amplifier design.

The operational amplifier chosen for this design will be the TLC2201CP from Texas Instrument. After consideration between the performances versus the cost, it had been decided that the TLC2201CP supports our needs and the cost is manageable as well. The TLC2201CP gain bandwidth goes up to frequencies as high as about 250kHz. The gain starts to decline as higher frequency components are introduced. The TLC2201CP operational amplifier produces very low noise at the output which prevents major distortions of our already weak signal. There are many factors that cause an amplifier to produce noise and the CMRR, Common Mode Rejection Ratio, is on one factor that helps determine the noise produce by the operational amplifier. The TLC2201CP CMRR in dB versus frequency can be found in Fig. 6. According to Fig. 6, the CMRR is very high, at about more than 100 dB, for low frequency signals of less than 1kHz. As the input signal exhibits higher frequency components, the CMRR starts to drop almost linearly per decade Hertz.

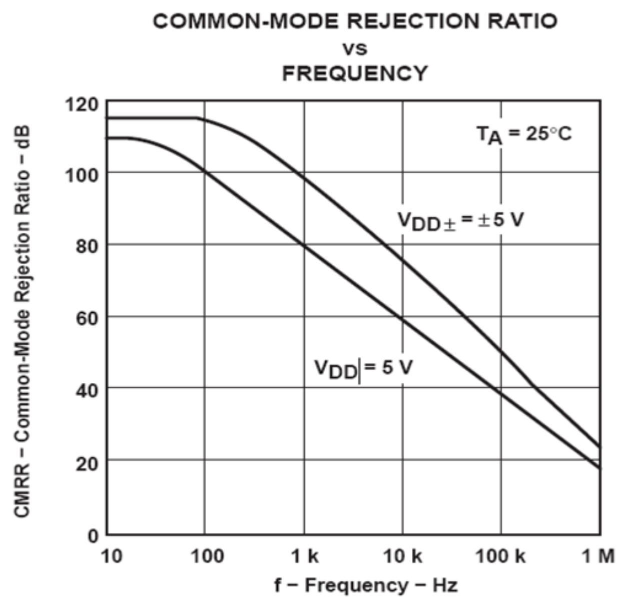

Fig. 6. CMRR in dB vs. Frequency graph for TLC2201CP Reprinted with permission from Texas Instrument.

Using the structure layout found in the Fig. 5, a schematic was designed for the amplifier system. The amplifier system schematic can be found in Fig. 7. In the schematic design, TLC2201CP operational amplifiers are used. The input signal comes from the MCT detector's output through the edge mount SMA connector. From there the signal is fed to the positive input terminal of the operation amplifier as well as the Drain pin of the N-channel MOSFET. The 5kΩ resistor will be connected from the negative input terminal of the operational amplifier to the output. There will be a 1kΩ resistor connected to ground (GND) on one node and the negative input terminal of the op-amp on the other node. The output of the first operational amplifier will be connected to three other pins. The first pin will be at the input another non-inverting operation amplifier with the gain of 6. The second connection will be made to the Source of the first N-channel MOSFET. Finally, the third connection will be to the Drain pin of the next n-channel MOSFET. This configuration allows the N-channel MOSFET to be used as switches to allow the signal to bypass the operational amplifiers or forced to travel through. The configuration is then repeated to have 6 non-inverting op-amps with switches for each one. Each of the gate pins from the N-channel MOSFETs will be connected to the I/O pins on the PCF8574. The final output from the last op-amp will be connected to an inverting unity gain op-amp filtering system. The filter was designed to filter any noise higher than 15 kHz.

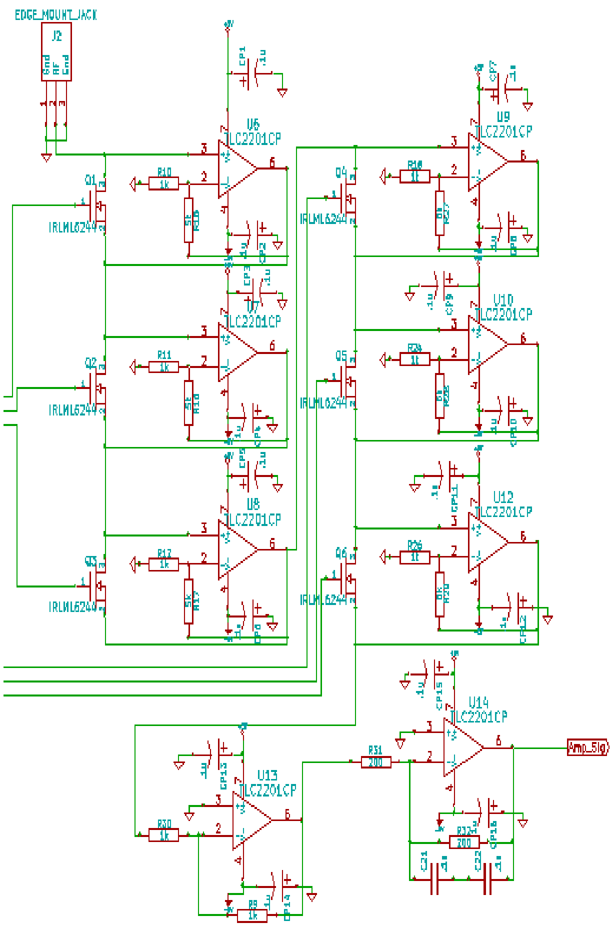

Fig. 7. Schematic of amplifier.

D. 24-Bits A/D Converter

The output signal from the amplifier will be need to be converted from analog signal to digital. Our design will use the NAU7802 to perform the task. The Nuvoton NAU7802 offers 24 bit analog to digital conversion, an onboard oscillator and a programmable low noise amplifier. The low noise amplifier will come in handy to amplify the output signal from the beam intensity detector so that the converter can recognize the low signal that will be in the nanoWatts range. The input signal may be internally amplified by up to 128 times. This IC also features an i2C operation which will allow it to communicate with the Atmega328 via 2 pins and have two more pins for power and ground, for a total of 4 pins to the Atmega. The i2C protocol allows for multiple devices to be connected in parallel, “Daisy chain,” and communicate over the same two lines. Because the i2C pins on the Atmega328 are also the analog input pins, the onboard Analog to Digital converter cannot be used in conjunction with this IC at the two pins being used for communication. The number of pins on the NAU7802 allows for up to two signals to be converted, so that any more than two signals will require another Nuvoton NAU7802 to be connected in parallel. The schematic found in Fig. 8 is how we plan to connect the NAU7802 with the Atmega328.

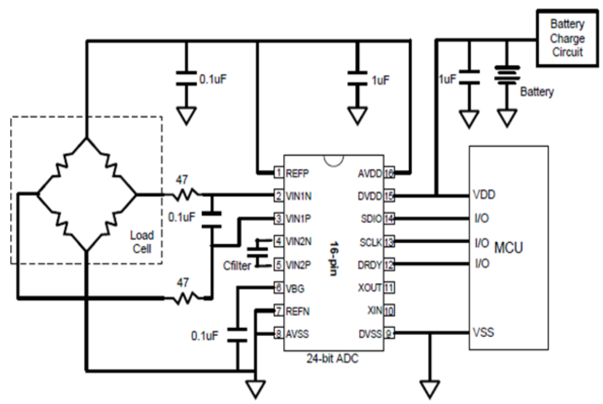

Fig. 8. Typical connection of the NAU7802 with a microcontroller used as a guide to connecting with the Atmega328.

E. Voltage Regulation

The first place that voltage regulation may be needed is to power the integrated circuits in the circuit. This includes but is not limited to the Atmega328, the NAU7802, the FT232R, and the LCD. The standard for USB power is 5V, while current depends on the USB version that the computer has and can range from 500mA to 900mA. For this reason, current will try to be minimized. If extra power is needed, a power supply may need to be designed or purchased. For this purpose a voltage regulator would be needed apart from the input DC supply. The ON Semiconductor MC33269D was chosen for regulating the voltage from the DC power supply because it has a simple configuration with only 3 leads. It is also very common and has been used in conjunction with the Atmega328 for many applications and has extensive documentation on their usage together. The output of the MC33269D is fixed at 5V but will drop with temperature and current consumption. If current consumption can be kept to a minimum, an external supply may be avoided in order to minimize wires and a need for an outlet near the experiment.

The second place that a voltage regulator may be needed is for the Analog reference voltage for the NAU7802, the 24 bit Analog to Digital converter. This reference voltage would ideally be kept at the perfect voltage at all times to keep accuracy as high as possible. This ideal voltage would be impossible to have even with a voltage regulator, but an attempt must be made for maximum accuracy. The lowest voltage regulator found is the Analog Devices ADR130 which is a high precision, low reference voltage that can output 500mV with 0.35% accuracy. It's able to get this accuracy because of an internal temperature drift curve that modifies its output voltage. The ADR130 is able to input a voltage range from 2 – 8v and output 0.5V; this is set up in the range of the USB supply voltage. From the 500mV output, a precision of 59.6nV would be possible with 23 effective bits of precision. If further precision is needed past the easily available 56.7nV, the reference voltage may be further divided to a lower voltage. The NAU7802 accepts a reference voltage as low as 0.1V, bringing the precision to 11.92nV which is the absolute minimum precision available from the NAU7802 unless the internal amplifier is used. The lower 0.1V reference voltage would be possible by using a voltage divider on the output and connecting a Unity Buffer Amplifier to keep the load off the resistors keeping them at a constant stable temperature. If the input is 1nV, the NAU7802 can amplify it by 128 times to 128nV. This would be within the range of the precision available from the 0.1V reference voltage. The precision needed to accurately measure the input signal is dependent on the lowest voltage that could possibly be input. If the second input voltage is above the AVref, a second ADR130 and NAU7802 will be needed.

The third voltage regulation that will be needed is to the power supply for the LCD screen. This screen has a total of 3 pins where a 3.3 supply voltage is needed. The first pin, V_{dd}, is for the power supply of the internal logic which only consumes roughly 1.5mA, or 2.5mA maximum. The supply voltage for the contrast for the LCD screen needs to be kept at approximately 3 volts, but for this a potentiometer can be used to tune the contrast to the desired amount as in the suggested wiring diagram given in the datasheet. The power supply for the LED backlight also requires 3.3V and pulls approximately 20mA. Typically the LCD will pull 21.5mA of current. For this purpose the L78L33C from STMicroelectronics was selected because of its low power dissipation. The L78L33C has a typical dropout voltage of 1.7V and can supply up to 100mA which is more than enough for LCD screen to work off. This is a typical 3 pin regulator with a V_{in}, ground, and V_{out}. The only supportive elements needed for it are two capacitors, one for the input, and one for output. A 0.33uF is recommended for the input pin and a 0.1uF is recommended for the output pin to help

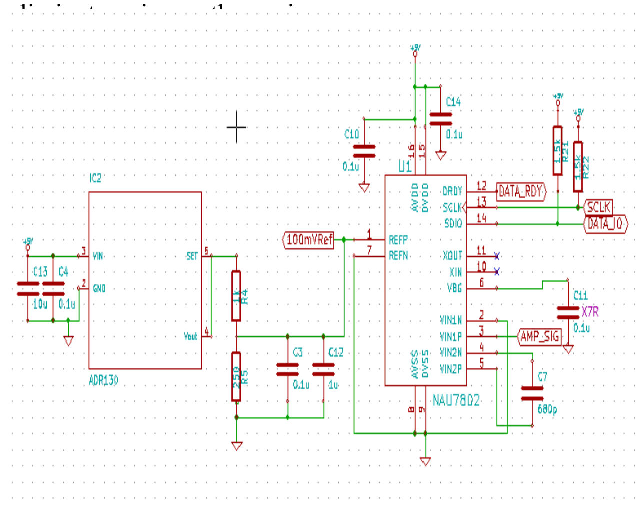

Fig. 9. Schematic showing an example of how voltage regulation is used for the NAU7802.

VI. Software

There are various features implemented to the software supporting the AOS system. The first and most important part will be the graphic user interface (GUI). The other parts include the raster scans, full scan and precise scan, and optimal position algorithm. These features will be further explained in the follow sections.

A. Graphic User Interface (GUI)

The GUI is organized into two main sections defined by the raster scans (full and precise). Both scans copy most of their features making it a logical choice to make the two GUIs as similar as possible. The main difference is that the precise scan has more settings. Thanks to the LabVIEW environment, editing the GUI is quick and easy to where any user can tweak the design to their desire. Also, thanks in part the graphical nature of LabVIEW, it is easy to add functions; therefore we created a clean simple design that can be extended.

A large part of the overall design was to use imagery to give context. Simple things such as the use of buttons shaped as arrows convey the direction of movement of our motors and graphs are implemented to verify orientation or the crystal. Scan data is even transformed into to a grayscale image in order to quickly show all the data gathered from that raster scan.

B. Raster Scan

The raster scan incorporates the essence of the program and project. As previously mentioned, it is very difficult to orientate the crystal by hand. Therefore, this setup and program will be to do just that. A scan will be done to find the intensity value at several positions and the position with the highest intensity, which also has surrounding high intensities as to avoid noise, will be made the new position. First a scan of the entire range of motor movements will be made to greatly narrow down where this desired position may be. The user will then use the manual operation program to move to where it looks like the desired position will be near, based on the displayed map, or the program will decide this position on its own. When this position is set, the precise scan will be used to make smaller and smaller rectangles, based on parameters set by the user. The user will also set how much the increments will be. The first time this scan is run, the user should pick a large scan size and increment size and each new scan should decrease both of those amounts until the correct position is eventually set. Fig. 10 shows just how complex this part of the program and how the precise requires more data and functions.

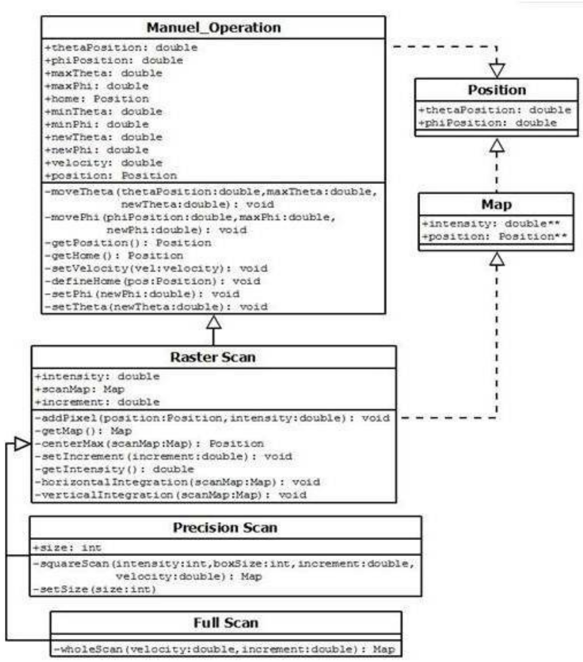

Fig. 10. Class diagram for the raster scans

C. Full Scan

The full scan is used to scan as much as the mount will be able to move, from one extreme to the other. It will create a map, represented as a grayscale image. This image is made based on the degree measurements of the motors (theta and phi) to represent the x and y components that make up the number of pixels and the intensity value of the light sensor to determine the value of each pixel. With the creation of this map, a function to determine the position of highest intensity based on surrounding pixels is ran and the motors will then move to this position. By observation of this map, the user is able to change this position. Various sources of noise could make it difficult for the program to choose between multiple possible positions. This scan should be the first part of the program to run in order to greatly narrow down the possible orientations the crystal may need to be at.

D. Precise Scan

Once some idea of where the correct orientation should be and the user is currently at that orientation then this part of the program should be run. After several runs, the optimal orientation of the crystal will be achieved. After each run the user should decreased the size of the scan, which must be an odd number, and/or the size of the increments. If time permits, a circle and oblong shaped scan will be added. The increments are the degrees amounts that the motors will move for each pixel. Therefore, both of these values determine the total size of the scan.

E. Optimal Position Algorithm

A simple method was used to determine the optimal position from the one of the raster scans. The two dimensional array of intensity data was integrated along its rows and columns. From these one dimensional arrays, we simply took the index location of each which represents an index location in the 2D array. We also have two other 2D arrays for the theta and phi position where each index matches in all three. Therefore, we can simple pull the value at that particular index location to get the position the motor was at when it reached its peak intensity. As long as the number of steps in the scan is not too small, noise from the signal will not be an issue. Furthermore this method does allow easy integration of noise reducing filters if the application calls for them.

VII. Conclusion

The Automated Optical Setup (AOS) project was done to support the OPO by automating many of its processes yielding higher efficiency and accuracy. The AOS is both hardware and software intensive. In hardware, the AOS implemented techniques of MOSFET switching, signal amplification and filtration, as well as analog to digital conversion. The core of the AOS rely on the software, which is responsible for analyzing the incoming data while adjusting the optical mount base upon those data. In addition, the AOS software will also provide a Graphic User Interface (GUI) allowing various features such as: amplifier gain adjustments, graph displays, and manual position adjustments using the LabVIEW environment. In the future, the applications of AOS can be expand to other optical experiments done at CREOL to improve their efficiency and accuracy.

Acknowledgement

We would like to thank the Laser Plasma Laboratory (LPL), headed by Dr. Martin Richardson, at the Center for Research and Excellence in Optics and Lasers (CREOL) for sponsoring this project. Special thanks to Dr. Larry Shah for managing the project with the interaction between our group and the graduate student working at LPL. These graduate students include: Pankaj Kadwani, Andrew Sims, Andreas Vaupel, and Benjamin Webb.

Biography

Chris Nergard will graduate with a Bachelor’s in Computer Engineering and continue to a Ph.D. in Electrical Engineering at the University of Central Florida (UCF). At the time of his graduation he would have had over two and half years of experience in the field of optics and lasers plus some prior research experience in various fields of computer science. He was also the Chair of the Institute of Electrical and Electronics Engineers (IEEE) student branch at UCF and Vice President of the American Society for Engineering Education at UCF.

Duy-Hung Pham is a 22 year old who will graduate with a Bachelor's of Science in Electrical Engineering in December 2012 at the University of Central Florida (UCF). He has done over 3 semesters of co-op works at the Aviation and Missile Research, Development and Engineering Center (AMRDEC) in Huntsville, Alabama. He is both a member of the Engineering Honor Society, Tau Beta Pi, and the Honor Society Phi Kappa Phi. After receiving his degree, he plans to start his engineering career while pursuing a Master degree in Electrical Engineer.

Roberto Borja will be graduating with a B.S. in Electrical Engineering and may continue his education after a few years of work experience. He has interned at Earthrise Space inc. on research park for a semester developing a lunar rover. He has been working fulltime as an intern for the past six months at NDI-RS in Longwood developing the firmware for a linux based intelligent camera that identifies license plates for law enforcement.

References

[1] National Instruments. (n.d.). *National Instruments Web Site*. Retrieved March-April 2012, from Common Mode Rejection Ratio: <http://www.national.com/AU/design/courses/268/par03/08par03.htm >.

[2] Newport Corporation. (2012). *Compact Piezo Driven Optical Mount, 1 inch Optic, Limit Switches*. Retrieved March-April 2012, from Newport Corporation: <http://search.newport.com/?q=*&x2=sku&q2=AG-M100L>.

[3] *DIY double sided board etching*. (2010, June 22). Retrieved April 10, 2012, from Instructables: <http://www.instructables.com/id/DIY-Double-Sided-PCBCircuit-Board-Etching/>.

[4] Cables To Go. (2012). *Cables To Go*. Retrieved February-April 2012, from Cables To Go - About DIN: <http://www.cablestogo.com/resources/din.asp>.