Progress Report: Microscope Mirror Control

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The construction of the electronic and software elements of the scanning laser microscope is on schedule. We have employed stepper motors to control the microscope's mirrors, allowing for laser scanning along two axes. The next major task is the synchronization of motor movement and photodiode data collection. Our microscope system is on track to be completed by December 4, 2018.

I. INTRODUCTION

In April, 2018, RedInk's R&D Department was tasked with designing and building a low-cost scanning laser microscope for commercial use. The operation specifications and mechanical housing were completed in August, 2018, at which point the project was handed off to the Yellow Team for software and electronics development.

The annual sales of confocal scanning laser microscopes likely exceed $150 million in the biological sciences, and similar microscopy techniques are essential for the semiconductor industry [1]. However, the price of most of these microscopes exceeds $10,000, limiting their use to large institutions [2]. A simple, low-cost scanning laser microscope would be of great interest for educational and training purposes.

A scanning laser microscope scans a focused laser beam in a raster pattern over a sample of interest. The light reflected off of the sample at any given point hits a photodiode and is converted to an electrical signal. These signals are used to create a 2D array of pixels that map the sample's reflectivity, providing the user with a high-resolution image.

In addition to reviewing our work so far, this report details our progress on the movable mirror element that enable the raster scanning of the imaging laser. The internal focusing mirror is controlled by two stepper motors to achieve both vertical and horizontal beam scanning. In turn, each of the motors is controlled by a dedicated stepper motor driver which receives instructions from an in-house LabVIEW VI's output on a National Instruments (NI) Data Acquisition (DAQ) card.

II. SUMMARY OF OVERALL PROGRESS

In the previous weeks, our group has experimented with timing methods using the NI-6221 I/O DAQ card and LabVIEW software. Using a hardware-timed counter, we were able to generate pulse trains of varying frequency and pulse width. Such timing elements form the backbone of the microscope's operations, including motor movement, data collection, and their synchronization.

Using a timer-generated pulse train, we created a LabVIEW VI to control the system's stepper motors. The VI allows for the independent control of each of the motors, isolating horizontal and vertical scanning. Furthermore, this VI allows the user to specify the motor's stepping rate and total number of steps. The high level schematic showing the pin numbers and arrangements of the components is shown in Figure 1.

In addition, we have constructed a photodiode circuit that generates a voltage proportional to the amount of light hitting the photodiode. We also designed an analog-to-digital conversion (ADC) VI that can convert the photodiode circuit's output to a more useful digital form. Thus far, the ADC has been used to isolate and quantify several sources of noise that may affect measurements.

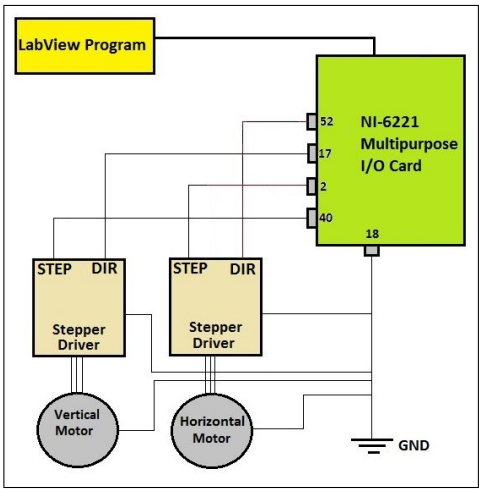

FIG. 1. ***High Level Schematic of Motor Control Interface:*** The stepper drivers are controlled from the LabVIEW Program using NI-6221 DAQ. Relevant control signals are STEP (the number of steps to turn) and DIR (clockwise or anticlockwise direction). Pin 18 is used as ground.

Presently, we are constructing a VI that will combine motor movement and photodiode data collection. This task requires precise, hardware-timed synchronization. Once this step is complete, all that remains is characterizing the microscope's resolution, developing a protocol for 2D raster scanning, and building a user-friendly GUI.

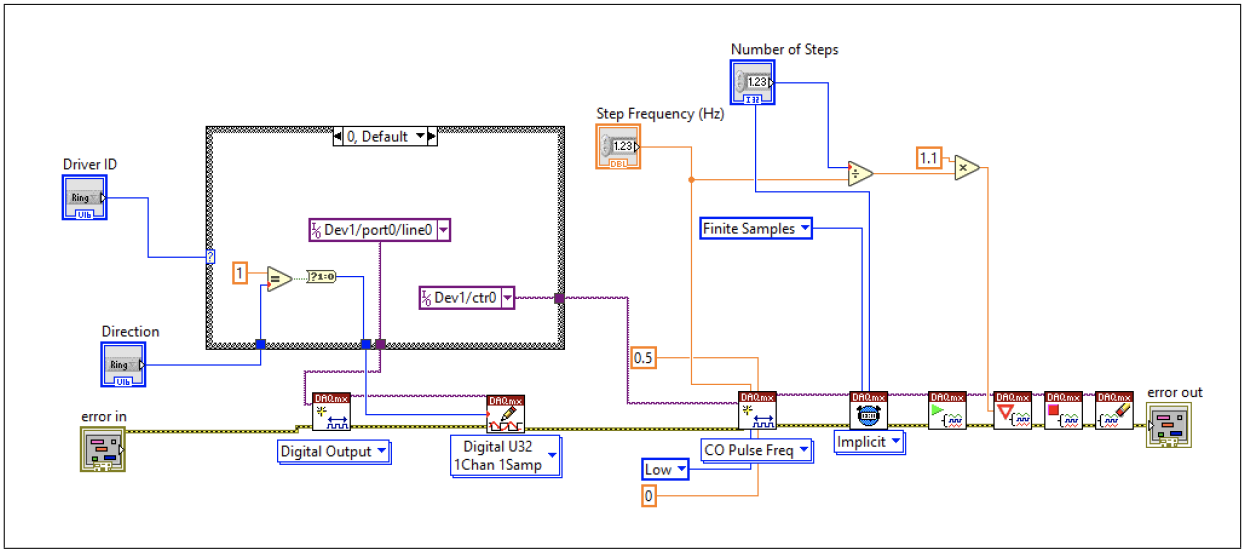

FIG. 2. ***Block Diagram of the LabVIEW Program:*** The block diagram accepts the user input from the front window to select the proper motor and rotation direction using the Digital Output task. The diagram then defines another output task, CO Pulse Freq, to move the motor by a user-defined number of steps at a set speed.

III. MOTORIZED MIRROR CONTROL PROGRESS

A. Hardware/Software Setup for Motor Control

The LabVIEW program to control the motors, as well as the physical connections of the stepper drivers with the motors and NI-6221 I/O DAQ card, are complete. The VI block diagram is shown in Figure 2. The program includes a task that writes to the DAQ card to output electronic pulses to the horizontal or the vertical motor. There is also a task that controls the direction of the motors, and this sets the output port on the DAQ card so that the motor can turn clockwise or counterclockwise. Each electronic pulse from the counter corresponds to one step of the stepper motors.

The front panel GUI for motor control is shown in (Figure 3). This LabVIEW VI allows the user to choose which motor to turn (vertical/horizontal), which direction to turn (clockwise/anticlockwise), the number of steps to turn and the step rate. These inputs will later be part of a larger, more comprehensive GUI for the control of the full microscope.

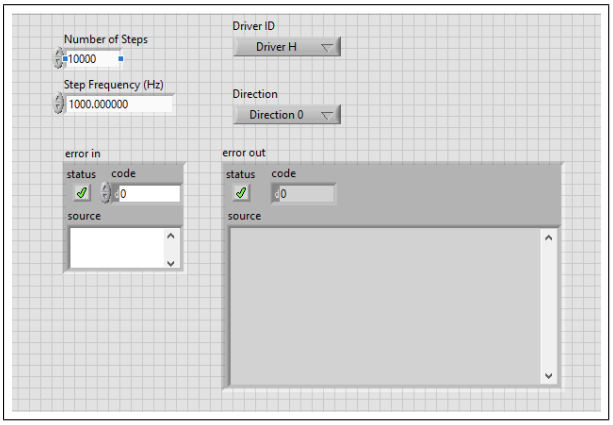

FIG. 3. ***Front Panel of the LabVIEW Program:*** The front panel allows us to select the motor and the direction of rotation. By specifying the number of steps and step rate for each motor, we will be able to precisely control each scanning mirror with two degrees of freedom.

B. Motor Functionality

We are operating the stepper motor in 1/16 "microstep" mode [3]. Since a step is defined by a rotation of 7.5°, 768 steps corresponds to a full rotation.

In order to test the reliability of the motors, we ran each motor ten times at a given rate. If the motor successfully completed its task, it was deemed a reliable motor at the tested speed. In general, we determined the maximum reliable step rate of all the motors to be 15 kHz. If the motor speed is slowly increased from this value for several minutes, step rates of up to 20 kHz are achievable. However, rates of this magnitude are not recommended as they often stall the motor.

Although we have tested the motors independently, we have not yet paired them to the scanning mirrors. The additional torque required to move the mirrors may reduce the maximum reliable step rate. This will require additional testing, but we believe that step rates in the range of $0.2 - 2$ kHz will be well within the microscope's safe operational limits.

IV. NEXT STEPS

In its current status, the design of the microscope is proceeding according to schedule, and each component of the instrument is functioning separately. We are currently writing a VI that will allow us to operate the motors and the photodiode synchronously.

The program we have created for the motors will be incorporated into the overall microscope VI, which will include an analog-to-digital (ADC) function that runs synchronously with the motors. The purpose of timing the motors and the ADC will be to ensure that the microscope collects data at regular intervals as the laser scans. We will complete our first trial run of a functioning microscope on a TEM sample grid on November 2.

The final step for our prototype is to create a software-hardware interface in LabVIEW that allows users to scan and capture 2D images. Using a simple GUI, the user will be able to control the size of the scan, the scan rate, and the number of data points to collect. The program will also display all measured data, as well as give the user the ability to stop and save the scan for further analysis. The entire microscope prototype is on track to be completed by December 4, 2018.

[1] W. B. Amos and J. G. White, *How the Confocal Laser Scanning Microscope entered Biological Research*, Biology of the Cell **95**, 335-342 (2003)

[2] Thorlabs (2018). Confocal Microscopy. Retrieved October 28, 2018, from `https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=10647`

[3] B. Schmalz (November 4, 2012). Big Easy Driver User Manual. Retrieved October 27, 2018, from `http://www.schmalzhaus.com/BigEasyDriver/BigEasyDriver_UserManal.pdf`