Synthetic Optical Holography Stage Implementation

ECE 445 Design Review

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Team #52
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1.0 Introduction

1.1. Statement of Purpose

Confocal Microscopy is an optical imaging technique for obtaining high resolution image mostly used in biological science. Confocal microscope uses point illumination method and discards any other stray light. Conventionally, Synthetic Optical Holography (SOH) is used for quantitative phase mapping of confocal microscopy by adding a linearly moving reference mirror. Using this method, the reference mirror needs long travel range for creating a linear-phase synthetic reference wave. Two methods are available to improve this drawback. One method is to oscillate the reference mirror sinusoidally, and the other method is to tilt and change the height of the glass slide where sample is located. Our design uses the method of changing the height and tilt the glass slide by using four piezo-electric controllers, which reduces the travel range compared to the conventional method.

1.2 Objectives

1.2.1 Goals and Benefits

- Implement SOH on a confocal microscope
- Control piezo individually and together
- Improve control accuracy
- Improve repeatability of four piezos
- Reduce the travel range of piezo controllers

1.2.2 Functions and Features

- Measure individual height of piezos
- Measure height of the sample
- Ability to tilt the glass top
- Control piezo by using computer user input
- Control piezo in nanoscale precision
2.0 Design

2.1 Block Diagrams and Flow Chart

![Block Diagram]

Figure 1. Block Diagram.
2.2 Block Descriptions

2.2.1 PC

Height input can be obtained from user and PC sends signal to two linear programmable voltage regulators using closed-loop system with feedback signals from 4 interferometers.

2.2.2 Linear Programmable Voltage Regulator

Programmable voltage regulator is a step down converter that converts 12V input to required voltage to send the voltage to the amplifier with the information given from PC.
2.2.3 Amplifier

Amplifies voltage received from voltage regulator to send the amplified voltage to piezo actuators.

2.2.4 Piezo Driver

There are 4 Piezo drivers that moves in z-axis in nanoscale precision with maximum displacement of 2.2 micrometers. Piezo drivers change height according to the voltage applied.

2.2.5 Interferometer

4 Interferometers are used to obtain height information of each piezo drivers in nanoscale to send the information to PC.

2.2.6 AC/DC Converter

Converts AC voltage received from wall outlet to 12V DC voltage to send it to DC/DC converter and the power supply for linear regulators.

2.2.7 DC/DC Converter

Converts DC voltage to different DC voltage for supplying power to amplifier and linear programmable voltage regulator.
2.3 Schematics and Simulations

![Gain of 10 Amplifier Circuit](image)

Figure 3. Gain of 10 Amplifier Circuit.

![Gain of 10 Amplifier Simulation](image)

Figure 4. Gain of 10 Amplifier Simulation.
2.4 Calculations

2.4.1 Amplifier Calculation

To achieve voltage from 0V to 120V to send it to piezo drivers, the voltage received from programmable voltage regulator are amplified with the gain of 10. Because negative pin of amplifier has high impedance, current through the negative pin is negligible. Using voltage divider rule and kirchoff’s current law, following equation can be used.

\[ V_{out} = \frac{R_1 + R_2}{R_2} V_{in} \]  \hspace{1cm} (1)

With the input voltage of \( V_{in}=1\text{V} \), \( R_1=9\text{k}\Omega \), \( R_2=1\text{k}\Omega \), \( V_{out} \) is calculated as equation 2.

\[ V_{out} = \frac{9k+1k}{1k} \times 1 = 10\text{V} \] \hspace{1cm} (2)

3.0 Requirements and Verification

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
<th>Points</th>
</tr>
</thead>
</table>
| 1. Piezo Drivers  
Piezo drivers stable for an hour without drifting 5 nanometers when drivers are lifted | 1. Piezo Drivers  
Measure difference in height of the piezo drivers after an hour using interferometer | 30 |
| 2. Piezo Drivers  
Repeatability must be within few nanometers | 2. Piezo Drivers  
Measure the variation in displacement with interferometer | 10 |
| 3. Piezo Drivers  
Must have precision of +/- 5% of input height | 3. Piezo Drivers  
Measure the actual height of glass top and compare with the input height | 10 |
| 4. Piezo Drivers  
Must have maximum displacement of more than 800 nanometers | 4. Piezo Drivers  
Measure the total displacement with interferometer with maximum voltage applied | 15 |
| 5. Piezo Drivers  
Must be able to withstand 2lb slide weight | 5. Piezo Drivers  
Operate Piezo Drivers with 2lb object placed on top of the glass | 5 |
| 6. Amplifier  
Must be able to output 12V | 6. Amplifier  
Check the minimum output | |
7. Regulator
Must be able to step down
12V DC input to variable
voltage output ranging from
1V to 12V DC

7. Regulator
Measure the minimum
output and maximum output
of regulator with multi-meter

8. Piezo drivers joint
When piezo drivers are lifted,
glass top should have x-y
displacement tolerance of
less than 1um.

8. Piezo drivers joint
Measure the x-y
displacement of the glass top
with interferometer

<table>
<thead>
<tr>
<th>7. Regulator</th>
<th>7. Regulator</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Must be able to step down 12V DC input to variable voltage output ranging from 1V to 12V DC</td>
<td>Measure the minimum output and maximum output of regulator with multi-meter</td>
<td></td>
</tr>
<tr>
<td>8. Piezo drivers joint When piezo drivers are lifted, glass top should have x-y displacement tolerance of less than 1um.</td>
<td>8. Piezo drivers joint Measure the x-y displacement of the glass top with interferometer</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 1. R&V Table

3.1 Tolerance Analysis

It is the most critical part of our project that piezo drivers are actuated in precision of +/- 5% of input height. To satisfy this requirement, the input voltage of piezo driver has to be precise. Moreover, piezo driver has to keep the stability no longer than 5 nanometers when it is actuated for an hour. As voltage is applied for an hour, the registers in amplifier are heated and it causes to increases resistances of resistors. Because the piezo driver has to be able to be lifted more than 800 nanometers. Because 5 nanometer is 0.625% of 800 nanometer, second requirement is more difficult to achieve.

In assumption that one of registers in amplifier is not heated up, the maximum tolerance of resistance that satisfy requirement can be calculated. When ‘A’ is the offset of R1 in Figure (3) and ‘B’ is the offset of R2 in Figure (3), following equations can be obtained.

\[
R_1 = 9k\Omega \times (1 + A) = (9000 + 9000A)\Omega \tag{3}
\]

\[
R_2 = 1k\Omega \times (1 + B) = (1000 + 1000B)\Omega \tag{4}
\]

By rearranging equation (1), following equation can be obtained.

\[
\frac{V_{out}}{V_{in}} = \frac{R_1 + R_2}{R_2} \tag{5}
\]

To satisfy the requirement above, output voltage of amplifier has to be within 0.625% of ideal value. By using equation (5), the ratio input voltage of piezo can be calculated as following because input voltage is not changed when resistances in amplifier are changed.

\[
\frac{V_{out, ideal} - V_{out, tolerated}}{V_{out, ideal}} = \frac{\left( \frac{V_{out}}{V_{in}} \right)_{ideal} - \left( \frac{V_{out}}{V_{in}} \right)_{tolerated}}{\left( \frac{V_{out}}{V_{in}} \right)_{ideal}} \tag{6}
\]
Therefore,

\[
\frac{V_{\text{out}}}{V_{\text{in}}}_\text{ideal} - \frac{V_{\text{out}}}{V_{\text{in}}}_\text{tolerated} = \frac{R_1 + R_2}{R_2} - \frac{R_1 + R_2}{R_2} \quad \text{(7)}
\]

In assumption that only R1 is heated up, the maximum offset of R1 (A) can be obtained from equation (7).

\[
0.00625 > \left| \frac{R_1 + R_2}{R_2} - \frac{R_1 + R_2}{R_2} \right| = \left| \frac{9000 + 1000}{1000} - \frac{9000 + A + 1000}{1000} \right| = \frac{-A}{1000} / 10 \quad \text{(8)}
\]

By calculation, maximum A = 62.5Ω, which is about 0.694% tolerance of 9kΩ. In assumption that only R2 is heated up, maximum offset or R2 (B) can be obtained from equation (7) as following.

\[
0.00625 > \left| \frac{R_1 + R_2}{R_2} - \frac{R_1 + R_2}{R_2} \right| = \left| \frac{9000 + 1000}{1000} - \frac{9000 + 1000 + B}{1000} \right| = \frac{-B}{1000 + B} / 10 \quad \text{(8)}
\]

By calculation, maximum A = 66.67Ω, which is about 6.67% tolerance of 1kΩ. Even though the maximum tolerances of registers to satisfy requirements are low, this can be improved by feedback loop in controller. Even though there is more tolerance than 7%, our design can meet the requirement by applying more input voltage through controller.

4.0 Cost and Schedule

4.1 Cost analysis

4.1.1 Labor

<table>
<thead>
<tr>
<th>Student</th>
<th>Hourly Rate</th>
<th>Total Hours Invested</th>
<th>Total*2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyunjae Cho</td>
<td>$30</td>
<td>250</td>
<td>$18750</td>
</tr>
<tr>
<td>Sung Hun Kim</td>
<td>$30</td>
<td>250</td>
<td>$18750</td>
</tr>
<tr>
<td>Ye Hyun Kim</td>
<td>$30</td>
<td>250</td>
<td>$18750</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>750</td>
<td>$56250</td>
</tr>
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</table>
4.1.2 Parts

<table>
<thead>
<tr>
<th>For</th>
<th>Item</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulator</td>
<td>LTC3886</td>
<td>2</td>
<td>$18.14</td>
</tr>
<tr>
<td>Regulator</td>
<td>USB-PMBus</td>
<td>2</td>
<td>$100</td>
</tr>
<tr>
<td>AC/DC Converter</td>
<td>Adaptor</td>
<td>1</td>
<td>$20</td>
</tr>
<tr>
<td>Piezo drivers</td>
<td>PL022</td>
<td>4</td>
<td>$200</td>
</tr>
<tr>
<td>Piezo drivers</td>
<td>Sphere end caps</td>
<td>25(sold in packs)</td>
<td>$31</td>
</tr>
<tr>
<td>Interferometer</td>
<td>Interferometer</td>
<td>Provided</td>
<td>$0</td>
</tr>
<tr>
<td>Amplifier</td>
<td>LTC1052CN#PBF</td>
<td>4</td>
<td>$25</td>
</tr>
<tr>
<td>ALL</td>
<td>Various Resistors, Inductors, Capacitors, FETs, Transformers, etc.</td>
<td>Varies</td>
<td>$100</td>
</tr>
</tbody>
</table>

Total $494.14

Table 2. BOM Table

4.1.3 Grand Total

<table>
<thead>
<tr>
<th>Section</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$56250</td>
</tr>
<tr>
<td>Parts</td>
<td>$494.14</td>
</tr>
<tr>
<td>Grand Total</td>
<td>$56744.14</td>
</tr>
</tbody>
</table>

Table 3. Cost Grand Total Table

4.2 Schedule

<table>
<thead>
<tr>
<th>Week</th>
<th>Task</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/12/2016</td>
<td>Prepare Project Proposal</td>
<td>Ye Hyun Kim</td>
</tr>
<tr>
<td>(Week 1)</td>
<td>Consult with Experts</td>
<td>Sung Hun Kim</td>
</tr>
<tr>
<td></td>
<td>Prepare Mock Design Review</td>
<td>Hyunjae Cho</td>
</tr>
<tr>
<td>9/19/2016</td>
<td>Contact Seller &amp; Order parts</td>
<td>Ye Hyun Kim</td>
</tr>
<tr>
<td>(Week 2)</td>
<td>Finalize Mock Design Review</td>
<td>Sung Hun Kim</td>
</tr>
<tr>
<td></td>
<td>Build precise logic diagram</td>
<td>Hyunjae Cho</td>
</tr>
<tr>
<td>9/26/2016</td>
<td>Practice on Microcontroller</td>
<td>Ye Hyun Kim</td>
</tr>
<tr>
<td>(Week 3)</td>
<td>Test Hardware parts (Piezos)</td>
<td>Sung Hun Kim</td>
</tr>
<tr>
<td></td>
<td>Design Control Logic</td>
<td>Hyunjae Cho</td>
</tr>
<tr>
<td>10/3/2016</td>
<td>Program Code for embedded system</td>
<td>Ye Hyun Kim</td>
</tr>
<tr>
<td>(Week 4)</td>
<td>Run requirements of Piezos</td>
<td>Sung Hun Kim</td>
</tr>
<tr>
<td></td>
<td>Test Microcontroller &amp; Piezos</td>
<td>Hyunjae Cho</td>
</tr>
<tr>
<td>10/10/2016</td>
<td>Review coding for Microcontroller</td>
<td>Ye Hyun Kim</td>
</tr>
<tr>
<td>(Week 5)</td>
<td>Verification test on individual</td>
<td>Sung Hun Kim</td>
</tr>
</tbody>
</table>
### Table 4. Schedule Table

<table>
<thead>
<tr>
<th>Date</th>
<th>Task Description</th>
<th>Responsible Person</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/17/2016</td>
<td>Debug Code</td>
<td>Ye Hyun Kim</td>
</tr>
<tr>
<td>10/17/2016</td>
<td>Combine 4 Piezos &amp; verification test</td>
<td>Sung Hun Kim</td>
</tr>
<tr>
<td>10/17/2016</td>
<td>Assemble external power source for MCU</td>
<td>Hyunjae Cho</td>
</tr>
<tr>
<td>10/24/2016</td>
<td>Finalize Code</td>
<td>Ye Hyun Kim</td>
</tr>
<tr>
<td>10/24/2016</td>
<td>Finish assembling all components</td>
<td>Sung Hun Kim</td>
</tr>
<tr>
<td>10/24/2016</td>
<td>Run tests on both hardware &amp; software</td>
<td>Hyunjae Cho</td>
</tr>
<tr>
<td>10/31/2016</td>
<td>Begin working on Presentation</td>
<td>Ye Hyun Kim</td>
</tr>
<tr>
<td>10/31/2016</td>
<td>Prepare for Mock Demo</td>
<td>Sung Hun Kim</td>
</tr>
<tr>
<td>10/31/2016</td>
<td>Ensure functionality</td>
<td>Hyunjae Cho</td>
</tr>
<tr>
<td>11/7/2016</td>
<td>Check Stability of the Piezo</td>
<td>Ye Hyun Kim</td>
</tr>
<tr>
<td>11/7/2016</td>
<td>Finalize Mock Demo</td>
<td>Sung Hun Kim</td>
</tr>
<tr>
<td>11/7/2016</td>
<td>Test/Debug Whole system</td>
<td>Hyunjae Cho</td>
</tr>
<tr>
<td>11/14/2016</td>
<td>Prepare Presentation</td>
<td>Ye Hyun Kim</td>
</tr>
<tr>
<td>11/14/2016</td>
<td>Prepare Final paper</td>
<td>Sung Hun Kim</td>
</tr>
<tr>
<td>11/14/2016</td>
<td>Prepare Demonstration</td>
<td>Hyunjae Cho</td>
</tr>
<tr>
<td>11/21/2016</td>
<td>Celebrate Thanks Giving Day</td>
<td>Everyone</td>
</tr>
<tr>
<td>11/28/2016</td>
<td>Final Presentation/Demos</td>
<td>Ye Hyun Kim</td>
</tr>
<tr>
<td>11/28/2016</td>
<td>Final Presentation/Demos</td>
<td>Sung Hun Kim</td>
</tr>
<tr>
<td>11/28/2016</td>
<td>Final Presentation/Paper</td>
<td>Hyunjae Cho</td>
</tr>
<tr>
<td>12/5/2016</td>
<td>Final Presentation/Demos</td>
<td>Ye Hyun Kim</td>
</tr>
<tr>
<td>12/5/2016</td>
<td>Final Presentation/Demos</td>
<td>Sung Hun Kim</td>
</tr>
<tr>
<td>12/5/2016</td>
<td>Final Presentation/Paper</td>
<td>Hyunjae Cho</td>
</tr>
</tbody>
</table>

5.0 Safety and Ethics

5.1 Safety

5.1.1 Electrical Concerns

In our design, the first step is by converting the signal from the power outlet of 110V AC signal to 12V DC signal. This process is powered by the outlet through a power cord which is protected by a plastic around the wire inside. Whenever the power cord is torn or uncovered, users should immediately stop all processes and turn off the power.
Afterwards, the users should purchase another power cord, or protect the uncovered cord by a friction tape. Be aware that any of the circuits should not be placed in extreme environments. Above 70°C temperature is hazardous to the modules and the power system.

5.1.2 Optical Concerns

Although we are indirectly using lasers for confocal microscope, users should avoid staring lasers directly. In order to image live cells, the power of the laser should be 0.2% of the 10mW source. This optical power may be trivial, but when exposed for long period of time, the eyes will likely to get unexpected harm.

5.2 Ethics

Our project is based on IEEE Code of Ethics, and was used as a guideline for ethical considerations

1. To accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;

   In order to implement a safe performance, we must use the confocal microscope only in the allowed lab. In addition, as mentioned in the ‘Safety’ part, users should not be handling any device or circuits in extreme environments.

2. To avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;

   This project will be performed along with Professor Paul Scott Carney. All intellectual property rights and patents will belong to Professor Carney.

3. To be honest and realistic in stating claims or estimates based on available data;

   All data we report on lab report or graphs will be based on the real experiment, instead of making it up. We will perform our experiment with total honesty.

4. To reject bribery in all its forms;

5. To improve the understanding of technology; its appropriate application, and potential consequences;
Conventionally, Synthetic Optical Holography (SOH) is used for quantitative phase mapping of confocal microscopy by adding a linearly moving reference mirror. Using this method, the reference mirror needs long travel range for creating a linear-phase synthetic reference wave. Consequently, in order to improve this drawback, our design uses the method of changing the height and tilts the glass slide by using four piezo-electric controllers, which reduces the travel range compared to the conventional method.

6. **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;**

In order to improve our technical competence, we will ask helps from professors and TAs. With help from their knowledge, we can get advice and consult about limitations and restrictions of the project.

7. **To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;**

In order to complete our project with precise measurements, we need to read many related papers for calculations. When any of their intellectual properties are used, we need to properly credit the contributions.

8. **To treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression;**

9. **To avoid injuring others, their property, reputation, or employment by false or malicious action;**

10. **To assist colleagues and co-workers in their professional development and to support them in following this code of ethics.**
6.0 References


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