# LOW COST MOTORIZED MICROSCOPE STAGE


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Client: Dr. John Puccinelli; Advisor: Dr. Joshua Brockman


## Problem Statement

**Design Motivation**

The UW-Madison BME teaching lab currently houses two inverted fluorescent microscopes. While these contemporary pieces of equipment are functional in their current state, they leave a great deal to be desired when it comes to laboratory efficiency. Motorized alternatives do exist, however, cost continues to be a factor limiting the exposure students have to this technology. Our client, Dr. John Puccinelli, has requested the generation of a low cost device that can solve this problem and make motorized microscopy available to students in the BME teaching lab

**Our Goal**

With a working budget of approximately $100, our team seeks to improve the precision and automation of these microscopes through the creation of a novel microscope stage moving device. This design will allow for sequential, automated imaging of coordinate-based locations on slides. The creation of this device will increase workflow efficiency by reducing the amount of time spent during data collection and flattening the learning curve for operating these pieces of teaching lab equipment. To remain competitive, design prototypes should be automated in both the X and Y directions and retain high precision and accuracy in translations (1 µm).

## Background

- One of the two inverted fluorescence microscopes in the lab is a manual version of the Nikon Ti-U.
  - Has hanging manual control knobs that move the stage along the X- and Y-axis
- New market available motorized models are very expensive with a price point between $70,000-$80,000 from the manufacturer [1].
- Available motorized stages require stage alteration, replacement, or fabrication of an accompanying microscope.
- The Zaber ASR series motorized stage (figure 2) [3]
  - Replaces/rebuilds current stage setup
  - Accurate within 12 µm
  - Costs between $5,000-$9,000 depending on what features selected or size purchased
- OpenFlexure project (figure 3) [4]
  - Open source
  - Includes files to 3D print the stage and microscope, parts list, as well as instructions on assembly and use.
  - Can achieve sub-micron (<1 µm) mechanical positioning
  - Costs approximately $200 to complete

Figure 1: Nikon Ti-U Microscope [2].

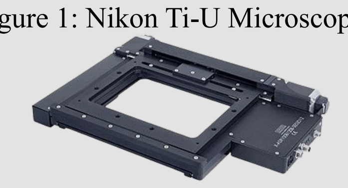


Figure 2: Zaber ASR series market available motorized stage [3].

Figure 3: OpenFlexture Block Stage [4].

## Past Designs

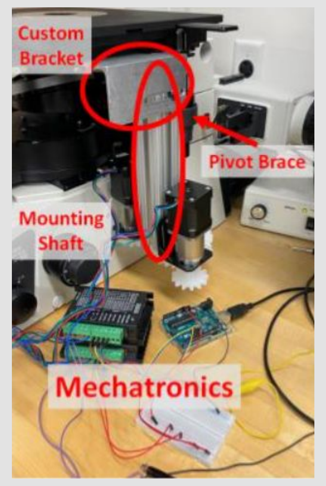



Figure 4: Fall 2020- Spring 2021 stage-mounted final design

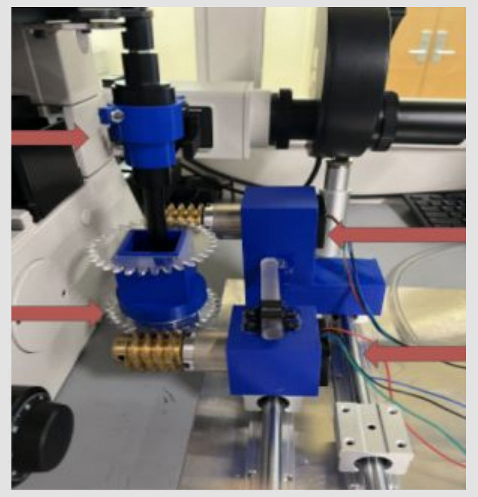


Figure 5: Fall 2021- Spring 2022 worm drive final design

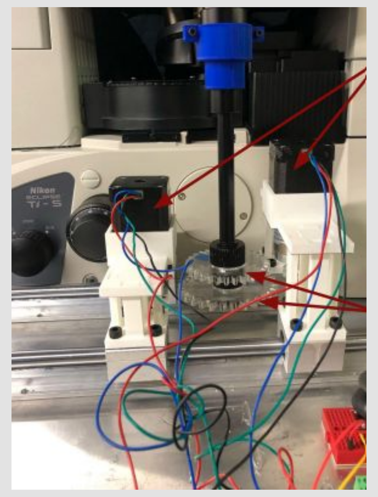


Figure 6: Fall 2022 linear rails final design

## Design Criteria

- The device must be a motorized mechanism that controls the stage movement through the manual stage adjustment knobs.
- The stage should be movable by using a joystick, computer keys, or by inputting values into the user interface.
- The movements of the stage should be precise down to the micron range, with acceptable deviations within one order of magnitude.
- The software created must be integrated into the existing NIS-elements software and assist in both taking images of the field of view and stitching them together.
- The device will be powered by the wall outlets in the lab.
- The project must remain under a final cost of 100 US dollars.

## Final Design

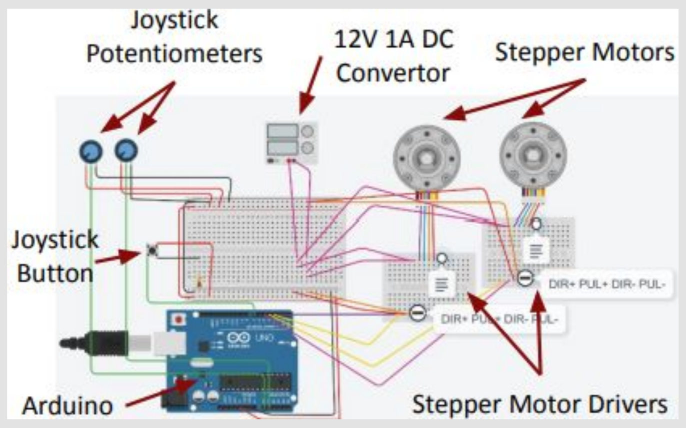



Figure 7: Motor Circuit Diagram

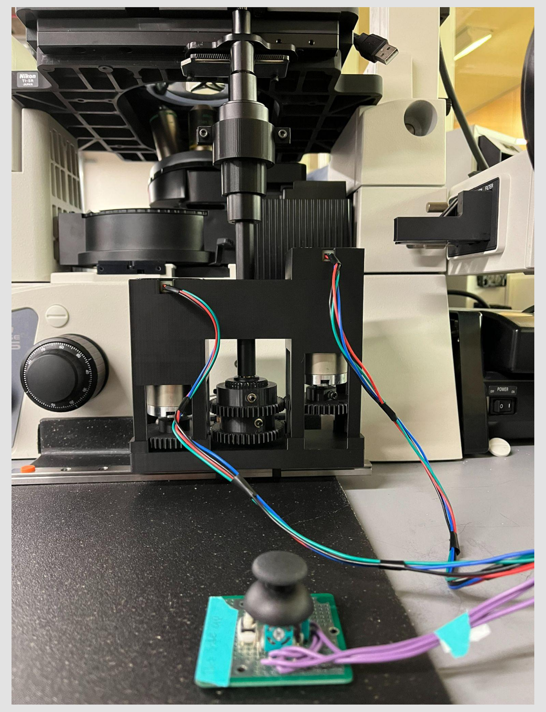


Figure 8: Assembled final design

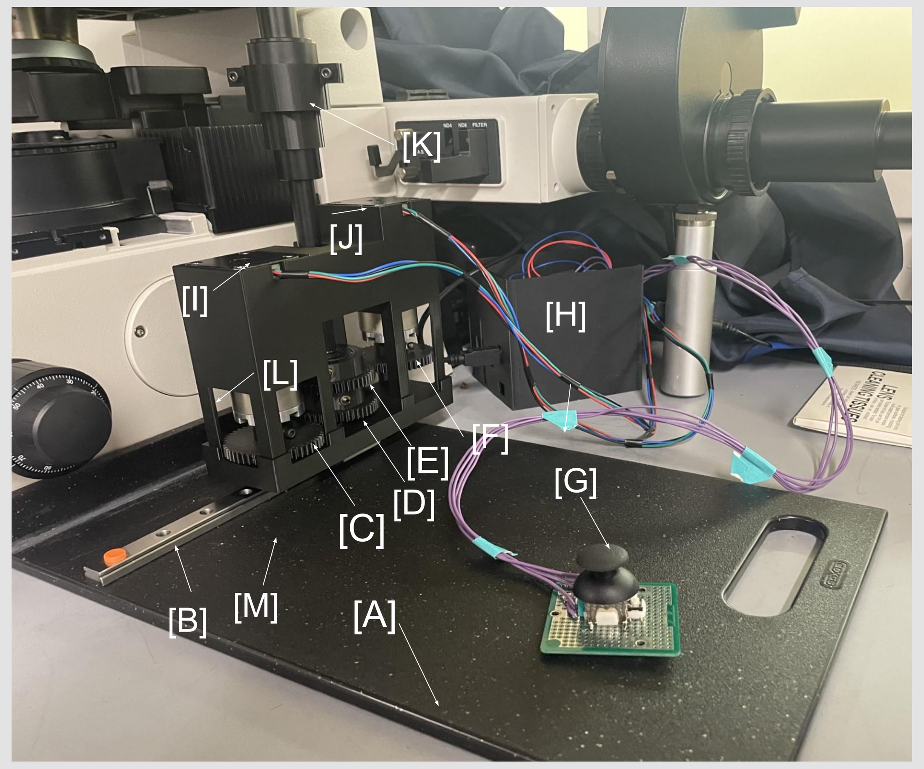



Figure 9: Elements on the final design: A) The Guide rail Mounting Plate (GMP) B) The linear guide rail C) The stepper gear driving X-axis movements D) The small (X-axis) knob gear E) The large (Y-axis) knob gear F) The stepper gear driving Y-axis movements G) The circuit-integrated joystick H) The Electronics Housing Unit (EHU) I) The stepper motor powering X-axis movements J) The stepper motor powering Y-axis movements K) A cuff designed by a previous group to assist in confining the movements of the microscope knob shaft L) The dual stepper motor housing unit and M) The sled mount.

**Total System Size** = 22.6cm x 9.9cm x 16.6cm = 3714 cm^3

- Surprisingly larger than previous group's reported dimensions by a factor of 4.806

## Fabrication

**GMP**

- Created from a 12x16 HDPE cutting board. Lip created by taking 2 inches of material off of the long edge and screwing and epoxying it to the cut edge. Finally, the GMP was dimensioned to fit flush to the microscope and preserve bench space.

**Sled Mount**

- Generated in CAD and 3D printed (3DP) in Bambu Labs X1-Carbon Printer. Works as an adapter piece to allow the large dual stepper mount to fit on a single carriage.

**Dual Stepper Mount:**

- Made through same CAD and 3DP. Designed to hold 2 stepper motors inverted and confine the knob shaft.

**Stiffening Cuff:**

- Created by a previous design team. Stiffens the microscope arm to reduce deflection.

**Stepper Motor Gears**

- Made though same CAD and 3DP. A single insert is later melted into the flat side of the print for set screw to go through.

**Microscope Knob Gears**

- Made in same was as stepper motor gears but with 3 inserts symmetrically around the center axis.

**Electrical Componentry**

- The overall circuit design can be seen in Figure 12. These components have been combined in to the EHU for aesthetics purposes.

**Software**

- Programming was done in the Arduino IDE.

Figure 10: The GMP

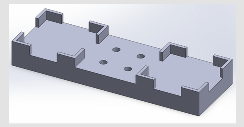


Figure 11: The sled mount

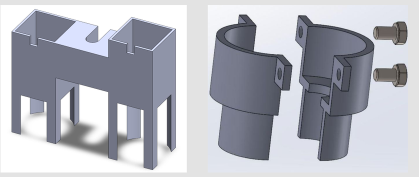


Figure 12: The Dual stepper mount (left) and the stiffening cuff (right)

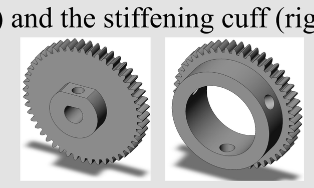


Figure 13: One of the knob gears (left) and one of the stepper gears (right)

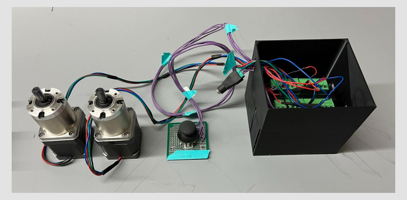


Figure 14: connected electrical componentry of the final design

Arduino IDE

Figure 15: Arduino IDE [5]

## Testing

Direct Connection

1. Connected a universal joint (Figure 16) directly to the x-axis knob of the microscope.
2. A starting image was captured after assuring no loss of motion would occur upon next step.
3. The device was automated to move a preset number of steps.
4. A final image was taken
5. All steps were repeated and then all images were analyzed in Fiji: ImageJ

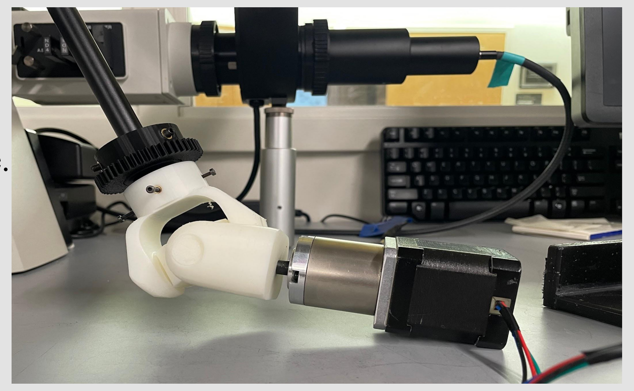


Figure 16: Universal joint connected to the X-axis knob of the Microscope

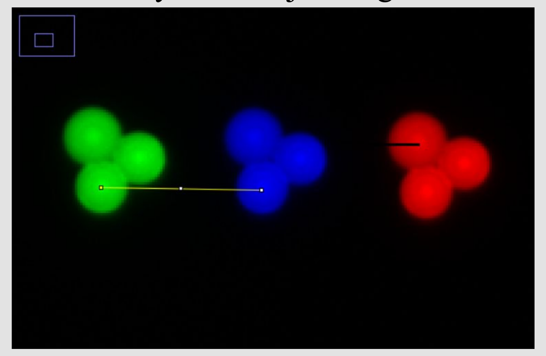


Figure 17: Loss of motion testing microscope images compiled together. The red clump is the starting position. The Green is final position. The blue is final position for attempting to move back to the start (data not used).

Loss of Motion Testing

1. After setting up the microscope, position the device so that is moves instantly when automated in one direction.
2. Capture a before image, making sure there is a visible clump at the edge of the screen.
3. Have the device move a predetermined amount of steps in the opposite direction as chosen above.
4. Capture a final image
5. Repeat ten times
6. Upload the images to Fiji: ImageJ, for analysis

Linear Testing

1. Set up the microscope.
2. Position the device so that there is no loss of motion in intended direction.
3. Capture a starting image, with a clump of beads clearly visible on the edge of the field.
4. Move the device a predetermined amount in the same direction as chosen above.
5. capture a final image.
6. Repeat ten times.
7. Upload the images to Fiji: ImageJ for analysis.

## Cost Break Down

Table 1: Fabrication expense breakdown.

| Materials | Place Purchased | Quantity | Cost |
|---|---|---|---|
| Arduino Uno | Makerspace | 1 | $10.00 |
| Stepper Motors | StepperOnline.com | 2 | $62.76 |
| Linear Rails | Amazon | 1 | $15.99 |
| 3D Prints | Makerspace | 347g of PLA | $27.76 |
| Cutting Board | Walmart | 1 | $12.44 |
| Screws and Electronics | Various Vendors | N/A | ~$7.00 |
| Total | | | $135.95 |

Direct Connection Testing

- The device is capable of moving an average of 1.41 µm per step of the motor.
- Allows for comprehension of the manual knob capabilities without errors occurred by the motorized device.

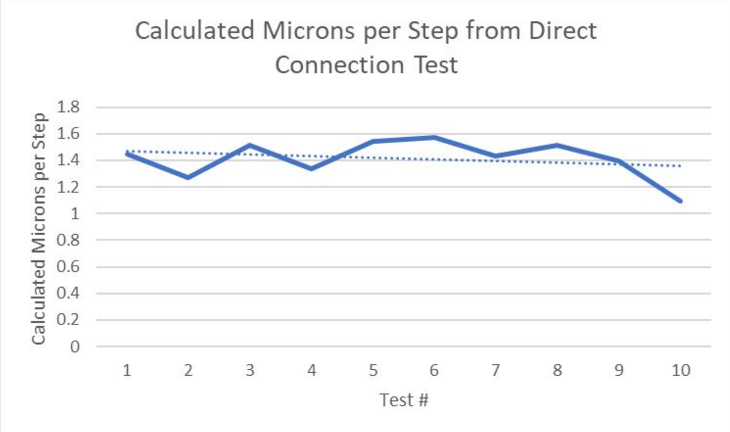


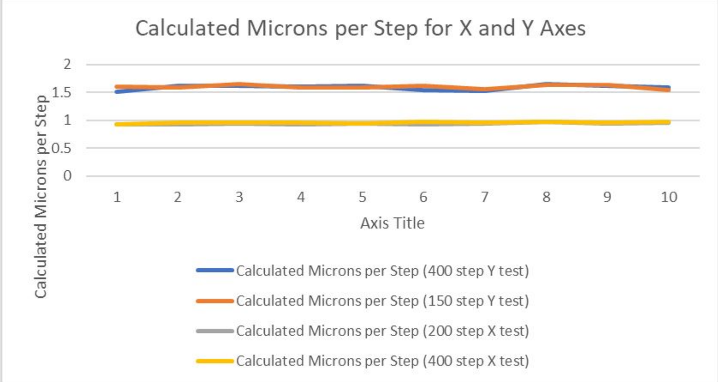

Figure 18: Graph representing the calculated microns moved per step of the motor corresponding to its trial number. The solid blue line represents the actual data and the dashed blue line represents the trend line.

## Results and Discussion

Analysis of Data Procedure

- Start and end images were overlaid using Fiji: ImageJ software, then distance between them was measured.
- Microns per step calculation: (measured travel) / (total steps traveled)
- Loss of motion calculation: ((steps traveled)*(calculated microns per step)) - (measured travel)

Figure 19: Graph representing the calculated microns moved per step of the motor corresponding to its trial number.




Linear Testing

- The device is consistently moved an average of 0.950 µm per step of the motor along the X- axis.
- The device is consistently moved an average of 1.593 µm per step of the motor along the Y- axis.
- The minimal fluctuation of the calculated value of µm per step shows consistency.
- Consistency allows for a general calculation to allow for a distance input rather than a step input.

Loss of motion Testing

- The X-axis consistently has to move an average of 48.35 steps of the motor before any movement is measured.
- The Y-axis has to move between an average of 290 and 340 steps of the motor before any movement is measured.
- Minimal fluctuation throughout the calculated value of loss of motion shows consistency in the X direction.
- Consistency allows for a general calculation to be imputed into the code to adjust for the loss of motion experienced by each axis.
- Inconsistency could occur due to poor gear meshing.

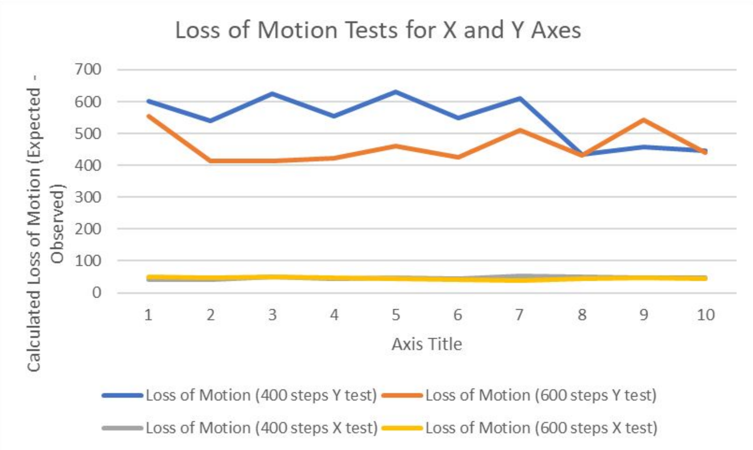



Figure 20: Graph representing the calculated microns moved per step of the motor corresponding to its trial number.

## Future Work

Short Term

- Refabricate gears with heat-set inserts
- Fine-tune 3D printed parts for more flush fit
- Trim GMP down to minimum length required to increase free bench space
- Fabricate mounting adapter plate
- Add feature to further stiffen knob shaft

Long Term

- Improve testing methods to provide more holistic description of design capabilities
- Explore alternative fabrication methods and materials to reduce fabrication cost
- Integrate ImageJ image stitching plugin into the existing microscope software


## Acknowledgements

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- Dr. Joshua Brockman
- Dr. John Puccinelli
- Dr. Amit Nimunkar
- Jesse Darley
- Past Design Groups


## References


[1]“Nikon Ti-U Inverted Fluorescence Motorized Microscope Pred Ti2 - AV.” Accessed: Oct. 13, 2023. [Online]. Available: https://www.bostonind.com/nikon-ti-u-inverted-fluorescence-motorized-microscope-pred-ti2-av

[2]“Buy Nikon Ti-U Microscope - EINST Technology Pte Ltd | EINST Technology Pte Ltd.” Accessed: Dec. 05, 2023. [Online]. Available: https://www.einstinc.com/wpcproduct/inverted-microscope-eclipse-ti-u/

[3]“ASR Series - Motorized Microscope Stages, XY - Zaber.” Accessed: Sep. 21, 2023. [Online]. Available: https://www.zaber.com/products/scanning-microscope-stages/ASR

[4]“The OpenFlexure project.” Accessed: Sep. 21, 2023. [Online]. Available: https://openflexure.org/

[5]“Arduino - Home.” Accessed: Dec. 06, 2023. [Online]. Available: https://www.arduino.cc/