Development of a Semi-Motorized Transfer Stage for Precise Manipulation of 2D Material Flakes in Photovoltaic Device Fabrication

Brayden Nicklus – Department of Mechanical and Aerospace Engineering

UNIVERSITY OF CENTRAL FLORIDA

The Center for Initiatives in STEM

Introduction / Background

- **The Importance of 2D Materials:** These materials (Figure 1) are vital for photovoltaic devices due to their tunable bandgaps and high electron mobility.
- **Challenge:** Commercial 2D material transfer system often cost over $20,000 which creates a barrier for smaller research labs.
- **Objective:** To produce a cost effective, semi-motorized transfer stage that automates the z-axis to enhance precision and reproducibility of flake isolation.
- **Summary:** The transfer system created automates the z-axis via a Nema 17 stepper motor and an Arduino Uno, achieving a resolution of a few micrometers for research applications.

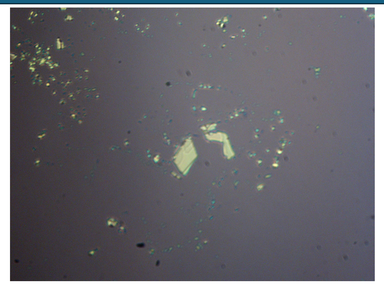


Figure 1: 2D material flake sample

Methods / Materials

- **Mechanical Integration:** Custom 3D printed motor mounts and couplings were designed to connect the motor shaft to the manual z-axis knob.
- **Hardware:**
  - **Motor:** A Nema 17 stepper motor providing 200 steps per revolution.
  - **Driver:** An A4988 driver module to translate digital signals into current pulses.
  - **Controller:** An Arduino Uno to execute firmware to manage motor logic and communication to the computer.
- **Firmware / Software:**
  - **Arduino IDE:** Used to develop code that is directly uploaded to the Arduino Uno which controlled the motor.
  - **Python IDE:** Used to develop the Graphical User Interface (GUI) to send signals to the controller to allow for the desired control over the motor.

Results

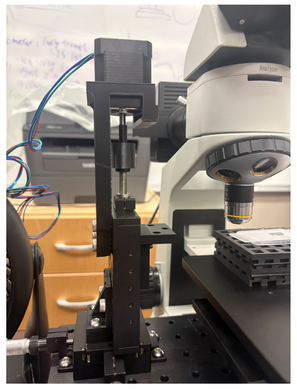


Figure 2: Transfer system

Mechanical Integration:

- The system successfully automated the z-axis by coupling a Nema 17 stepper motor to the manual knob of the transfer stage.
- Custom 3D-printed mounts and couplings were designed to ensure rigid rotation transfer between the motor shaft and the stage hardware (Figure 2).
- This integration allows the stage to fit onto a standard laboratory microscope for real-time monitoring of flake isolation.

Electrical Circuit:

- The Arduino Uno executed firmware that parses commands from the computer and potentiometer. The Uno's digital ports 2 and 3 were utilized for STEP and DIR (direction) signals and the A0 port was used for the analog signal of the potentiometer.
- The A4988 driver acted as a precise current translator, converting the digital control signals from the Arduino Uno into physical motor pulses.
- These components are connected via a breadboard (Figure 3), which is powered by a 12-volt power supply.

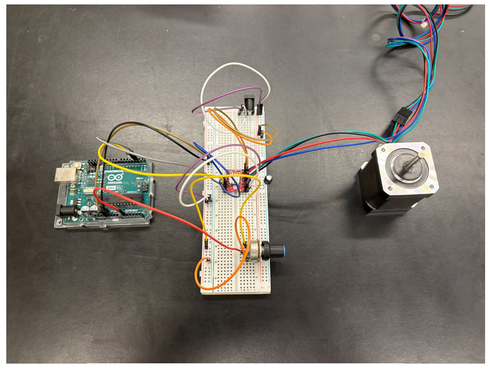


Figure 3: Transfer system circuit

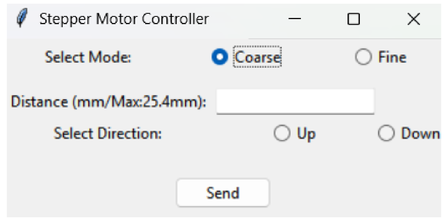


Figure 4:Graphical User Interface (GUI)

```
// Potentiometer mode
if (mode == 1) {
  // Potentiometer averaging
  totalPotReadings = totalPotReadings - readings[readIndex];
  readings[readIndex] = analogRead(pot_pin);
  totalPotReadings = totalPotReadings + readings[readIndex];
  readIndex = (readIndex + 1) % numReadings;
  averagePot = totalPotReadings / numReadings;

  long targetStepsFromPot = map(averagePot, 0, 1023, 0, 1400);

  if (abs(targetStepsFromPot - stepper.currentPosition()) > deadband) {
    stepper.moveTo(targetStepsFromPot);
  }
}
```

Figure 5: Transfer system code snippet

Software Control, Logic, & Signal Refinement:

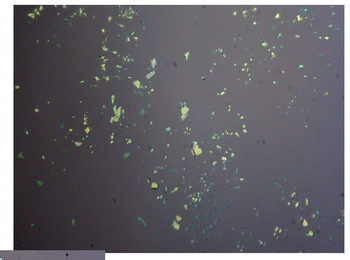
- A custom Python GUI (Figure 4) allows users to toggle between Coarse mode for distance targeting and Fine mode for potentiometer-based adjustments.
- To achieve micrometer resolution, the firmware converts a user defined distance into a specific step count based on the motor's resolution based on the following equation:

$$Steps = \left(\frac{200}{0.1491}\right) \times Distance$$

- To resolve motor "twitching" caused by analog signal noise from the potentiometer, a signal smoothing algorithm was implemented in the firmware (Figure 5).
- The GUI features a "Submit" button to transmit command signals via serial input, serving as a confirmation step to prevent accidental stage actuation.

Conclusion

- The developed semi-motorized transfer stage proved to be a highly cost-effective alternative to commercially available counterparts.
- The system successfully achieved the desired positioning control, meeting the target resolution of down to a few micrometers.
- The resolution can be refined even further if needed using micro stepping via the A4988 driver module.
- The dual control modes enhance user precision, facilitating the delicate operations required for the extraction of material flakes (Figure 6) for photovoltaic device production.



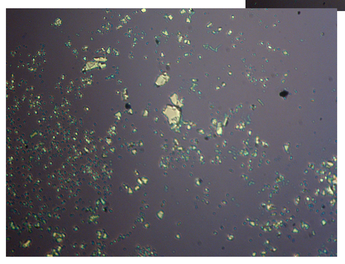


Figure 6: More 2D material flake samples

References

- Dejan. "Stepper Motors and Arduino - the Ultimate Guide." *How to Mechatronics*, 15 May 2022

Acknowledgements

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