Ellipsometer Automated Leveling System

Technical Design Document

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March 31, 2025

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Executive Summary

This project focuses on the design and development of an automated leveling system for the RC2 Ellipsometer, used in precision surface testing. Our primary goal is to reduce workload and speed up testing. The system uses a lookdown detector and servo motors, controlled by a ClearCore microcontroller, to automatically level the test sample.

By automating core functionalities and retaining manual control, our system reduces user workload while maintaining compatibility and precision. The apparatus is removable, integrates easily with existing test setups, and aims to provide a cost-effective alternative to commercial solutions.

1 Introduction

The Ellipsometer Automated Leveling System enhances precision and efficiency in aligning samples for ellipsometric measurements. Using a laser-based tilt detection system and servo-driven screw adjustments, it minimizes human error and streamlines the alignment process for high-throughput and high-accuracy surface testing.

2 Scope

This document details the design of the automated leveling system, including requirements, constraints, design logic, hardware/software implementation, and testing. It excludes user operations and measurement procedures, which are documented separately in the user manual.

3 Design Overview

3.1 Requirements

Functional Requirements

- Detect sample tilt using a laser and 2D lateral-effect position sensor.
- Automatically adjust leveling screws via servo motors.
- Toggle between manual and automatic leveling modes.
- Interface with ClearCore and USB debugging.

Performance Requirements

- Achieve tilt correction within ± 0.2 units in under 3 seconds.
- Maintain level without disrupting measurements.

Interface Requirements

- ClearCore GPIO compatibility.
- Toggle switch for mode selection.

3.2 Constraints

- Physical: Must mount externally, be removable, and avoid laser path interference.
- Cost: Total system budget under $2,400.
- Power: Operates from two 24V DC with step-down converters.
- Safety: Laser beam intensity attenuated via ND filter.
- Time: Completion within two academic semesters.

3.3 Dependencies

- External 120V AC power source
- Flat, reflective sample surface
- Microchip Studio with ClearCore SDK
- USB programming interface

3.4 Theory of Operation

A 635 nm laser reflects off the sample surface onto a ThorLabs PDP90A lateral-effect sensor. The sensor detects displacement from level, which the ClearCore controller uses to compute necessary corrections. It sends commands to ClearPath servo motors that adjust the sample's leveling screws via a belt drive.

3.5 Design Alternatives

3.5.1 Motor Selection

Stepper motors were initially considered due to their low cost and simplicity. However, they were ultimately rejected because they lack closed-loop feedback and are prone to missed steps, especially under load. To ensure reliable and precise alignment, servo motors with integrated control logic were selected instead.

The chosen ClearPath-SD servo motors feature a Step & Direction interface compatible with the Teknic ClearCore controller. These servos include automatic tuning capabilities that optimize performance for the specific application and load. Their integrated design eliminates the need for separate motor driver wiring, reducing system complexity and potential failure points.

Other advantages include:

- Closed-loop positioning, which eliminates concerns about missed steps
- Whisper-quiet operation, avoiding the audible whine typical of stepper motors

3.5.2 Sensor Selection

Quadrant Position Photodiode Detectors (QPDs), such as the ThorLabs PDQ80A and PDQ30C, were considered as potential alternatives due to their ability to determine beam displacement by comparing photocurrent across segmented regions. However, these detectors rely on intensity profiling and segmented detection, which inherently limits their resolution and introduces nonlinearity, particularly near quadrant boundaries.

The ThorLabs PDP90A 2D lateral-effect sensor was ultimately selected for its superior linearity, continuous position output, and cost-effective design. Unlike QPDs, the PDP90A operates using a tetra-lateral position-sensing mechanism, where photocurrent is distributed proportionally across a resistive layer and four corner-mounted electrodes. This "pincushion" design enables highly linear performance across the 9 mm $\times$ 9 mm active area, with accuracy comparable to more expensive duo-lateral sensors.

Additional advantages of the PDP90A include:

- Analog output in both X and Y axes, ideal for continuous feedback loops
- High resolution suitable for precision optical alignment tasks
- Compatibility with the 635 nm laser wavelength used in the system
- Cost-effective alternative to duo-lateral designs due to simplified structure

These characteristics made the PDP90A an optimal choice for accurate and responsive tilt detection in the automated leveling application.

3.5.3 Laser Selection

The PL204 laser module from ThorLabs was selected as the light source for this system. The key factors influencing this decision were:

- **Cost:** The PL204 is a cost-effective, off-the-shelf component with sufficient beam quality and output power for position-sensing applications.
- **Wavelength Compatibility:** Operating at 635 nm, the laser falls well within the operating range of the PDP90A lateral-effect sensor, which supports wavelengths from 320 nm to 1100 nm. This ensures reliable detection and signal strength without oversaturating the sensor.

An alternative considered was a tunable laser source. Such a laser would have allowed precise adjustment of output power and wavelength to potentially improve the resolution and signal-to-noise ratio of the PDP90A. However, tunable lasers are significantly more expensive and complex to integrate, and the marginal gains in resolution did not justify the increased cost and design complexity for this application.

The PL204 thus provided a practical balance between performance, simplicity, and cost.

3.6 Software

The program `SeniorProject.cpp` implements an automatic leveling system for a J.A. Woollam RC2 Ellipsometer. The system uses a lateral effect position-sensing detector and a laser to monitor the position of the beam reflected from the sample surface. Based on the beam's displacement, the program computes if the test bed has deviated from its leveled position. If it has, two ClearCore-controlled stepper motors make precise adjustments in the X and Y directions to restore the correct alignment.

The software runs continuously on the Teknic ClearCore microcontroller. It averages voltage readings from three analog inputs (X, Y, and SUM) and determines whether any deviation from a previously recorded level position exceeds a defined tolerance threshold. When the "leveling" switch is turned on, the system records the current position as the baseline and proceeds to adjust the motor position if deviations are detected. The program alternates between checking X and Y directions, with a 75 ms delay between each sample set.

Safety mechanisms include automatic motor alert handling and LED indicators to warn if the laser signal is lost. The system disables motors when not actively leveling, allowing manual adjustment.

3.7 Function Descriptions

main()

The `main` function initializes the hardware configuration and enters a loop that:

- Reads analog voltages from three ClearCore connectors.
- Converts these voltages to floating-point values for processing.
- Averages 10 samples to reduce noise.
- If the system is in "leveling" mode, it:
  - Enables the motors.
  - Sets a reference level position if it's the first loop.
  - Checks if the laser is off the sensor (low SUM voltage).
  - If the sample has shifted beyond X or Y tolerance, moves the motors accordingly.
- If not leveling, it disables the motors.

MoveDistanceX(int32_t distance)

This function moves the X-axis motor by a specified number of step pulses. It:

- Checks if there is a motor alert and handles it.
- Sends a move command to the motor.

- Waits for the motor's HLFB (High-Level Feedback) to assert that the move is complete.

This function enables precise micro-adjustments based on laser deviations in the X direction.

MoveDistanceY(int32_t distance)

Same as `MoveDistanceX`, but for the Y-axis motor. Ensures the Y adjustment happens only if it is safe to do so.

HandleAlertsX()

This function resets fault conditions for the X-axis motor. It:

- Disables the motor momentarily.
- Waits 10 ms.
- Re-enables the motor and clears all alerts.

Used to recover from faults like overload or signal loss.

HandleAlertsY()

Identical in structure to `HandleAlertsX()`, but for the Y motor. Keeps the system in a recoverable state after motor errors.

3.8 Power System

- **Laser Power**: The PL204 laser module requires a regulated 5V supply. A DC-DC converter is used to step down from the 24V system voltage to 5V.
- **Sensor Power**: The PDP90A sensor requires a split supply of ±5V. A dedicated DC-DC converter is used to generate this bipolar voltage from a 24V input.
- **Motor Isolation**: The ClearPath-SD motors are powered by a separate 24V power supply, isolated from the logic and sensor power domains. This prevents noise and back EMF from interfering with sensitive analog circuitry.

4 Testing

Test	**Procedure**	**Expected Result**	**Requirement Verified**
Sensor Detection	Manually tilt sample	Beam offset detected	Functional

Motor Adjustment	Enable auto with tilt present	Leveling completes in ¡3s	Performance
Manual Switch	Flip toggle to manual	Disables auto mode	Interface
System Safety	Power cycle during test	Motors halt safely	Constraint

5 Conclusion

The system meets all major design requirements, providing consistent and quick leveling without affecting the operation of the ellipsometer. While not being able to level maintain the sample level within 0.2 units it still provides a significant increase in performance compared to results without the system. The servo-based mechanism and ClearCore controller delivered reliable performance in lab testing. Future improvements include GUI integration, wireless controls, using the software level for adjustments, and beam positioning testing.

6 Appendices

6.1 Wiring Diagram

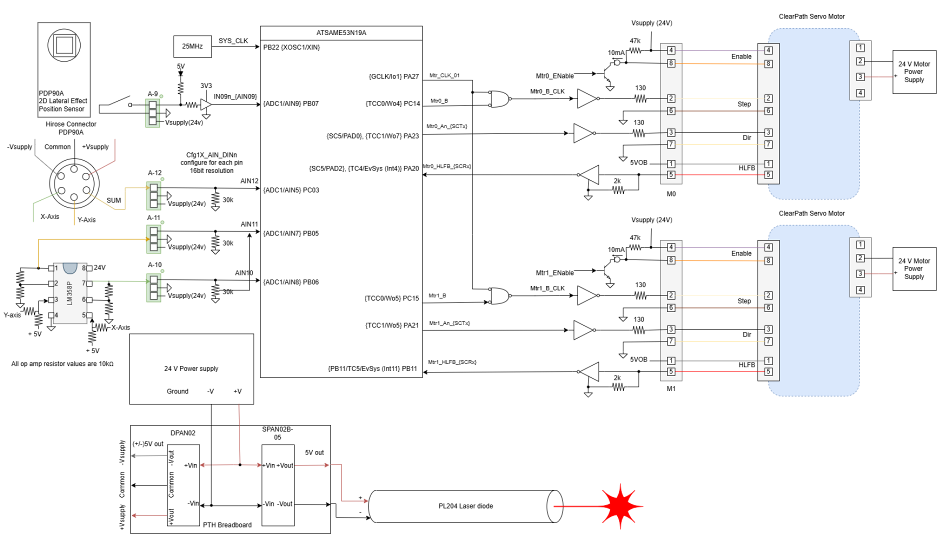

Figure 1: Full System Wiring Diagram

6.2 Source Code

All source code can be found at: https://github.com/TheDocotor/Senior-Project

6.2.1 C++

- SeniorProject.cpp (main) - Used in normal operation of leveling. No serial output.
- SeniorProject.cpp (SerialPrint) - Used in conjunction with EllipData.py to send voltage information from clear core and compiles data into a CSV that chan be processed by SerialData.py.

6.2.2 Python

- EllipData.py - Used to gather the serial data from the ClearCore. Compiles the data into a CSV that can be processed by SerialData.py
- CompleteEase.py - Used to plot the level data as seen in the CompleteEase Software. Useful to average multiple runs or compare runs to original alignment prior to installation of the system.
- SerialData.py - Used to plot the position on the sensor based on data collected by EllipData.py. Also provides standard deviation, mean and max deviation from center.

6.3 CAD Files

The following CAD files are included in the project archive and can be found at:
https://github.com/TheDocotor/Senior-Project

- `TopMount.stl` – 3D-printed bracket for sensor and laser
- `TopMount.step` – 3D-printed bracket for sensor and laser
- `MotorMountX.stl` – Servo motor mount for X
- `MotorMountX.step` – Servo motor mount for X
- `MotorMountY.stl` – Servo motor mount for Y
- `MotorMountY.step` – Servo motor mount for Y
- `AdjustmentKnob.stl` – Cap for adjustment knobs
- `AdjustmentKnob.step` – Cap for adjustment knobs

6.4 Component Datasheets

All data sheets are included in the project archive and can be found at:
https://github.com/TheDocotor/Senior-Project

6.5 Bill of Materials

Component	Part Number	Qty	Notes
PDP90A Sensor	PDP90A	1	Lateral-effect sensor
PL204 Laser	PL204	1	635 nm beam
Absorptive ND Filter	NE510A	1	25% light transmission
DC-DC Converter (5V)	SPAN02B-05	1	24V to 5V
DC-DC Converter (±5V)	DPBW03F-05	1	24V to ±5V
ClearCore Controller	CLCR-4-13	1	Motion and I/O control
Atmel-ICE Debugger	ATATMEL-ICE-BASIC	1	Debugger for ClearCore
Atmel-ICE to ClearCore	TC2030-CTX-LEMTA	1	Cable for debugger
ClearPath Servo Motors	CPM-SDSK-2310D-ELN	2	Level adjustments
Power Supply	LRS-150-24	2	24V DC supplies
Op-Amp	296-1395-5-ND	1	Sensor voltage offset
3D Printed Mounts	–	5	Sensor, laser, motor, and adjustment knob models
2-Pin Molex Plug	WM20244-ND	2	Modular connector for laser
2-Pin Molex RCPT	WM13486-ND	2	Companion to 2-pin plug
4-Pin Molex Plug	WM16259-ND	3	For motor power cabling
4-Pin Molex RCPT	WM16165-ND	1	Companion to 4-pin male
8-Pin Molex Plug	WM26395-ND	5	Motor control to ClearCore
8-Pin Molex RCPT	WM13488-ND	1	Companion to 8-pin male
Terminal Block Plugs	CC-3TERM-PLUG-10PC	5	Companion to 8-pin male
Switch	–	2	Toggles for power and leveling control
Hirose RCPT (F) 6P	HR1594-ND	1	For sensor to enclosure
Drive Belt	124L050NG	2	Belt to connect motor shaft to adjustment knob
Timing Pulley	APB13L050BF-375	2	Conenction point for the motor shaft
Power Receptacle	CCM1784-ND	1	Power cable receptacle
Power Cable	Q988-ND	1	Cable for wall outlet

Table 2: Bill of Materials