A Compact Material Modulus Measurement Instrument

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Chapter 1

Introduction

1.1 Background and Objective

Soft materials, such as hydrogels and polymers, play a crucial role in various applications, including biomedicine, protective coatings, and electronics. Accurate mechanical characterization of these materials is essential for their effective design and implementation. However, current measurement systems face significant challenges in ensuring precision. On the other hand, strain gauge based Wheatstone bridge is applied in sensing system. The zero shift of the Wheatstone bridge and the Johnson–Nyquist noise of the resistors may leads to measurement inaccuracy. Electromagnetic Interference will also generate significant noise. Since the circuit will integrate ADC, the refection of magnetic wave of the transmission line may leads to Bit Error Rate. Since measurements always involve errors, multiple measurements are necessary. Manually performing repeated measurements, collecting data, and analyzing results is a tedious task. A user-friendly graphical control and data analysis software will significantly improve efficiency.

The project will develop a macro-scale instrument replicating the functionality of an atomic force microscope (AFM) for measuring the mechanical modulus of soft materials. The mechanical design will feature a precision-controlled indentation system, consisting of a motor-driven lead screw and a specially designed cantilever attached with a spherical probe. At the same time, the circuit should develop an low power EMI reduction system that provide extremely accurate measurements. The circuit will optimize the PCB rounting to eliminate the reflection. A good software system can also reduce the measurement iterations as the software features a user-friendly interface that allows users to perform measurements through simple buttons and input fields while displaying the results in real time. It can correct and analyze data, automatically select the appropriate contact model, and calculate the Young's modulus.

1.2 Visual Aid



Figure 1.1: Solution in Context

1.3 High-Level Requirement List

- The mechanical system shall provide a stable mounting platform and enable precise linear motion with a resolution $\leq 1 \ \mu$ m, while the cantilever shall have a spring constant at least 10× greater than the sample's effective stiffness under quasi-static contact.
- The circuit should enables accurate signal measurement and processing with minimized EMI. The PCB design ensures proper impedance matching to prevent signal reflection and loss. The control system must precisely control the stepper motor with the required resolution.
- The control system must accurately and completely transmit control and data signals between the strain gauge, upper-level software, and motor driver. The upper-level software must accurately convert the strain gauge signal into force and derive the force-displacement curve based on the stepper motor displacement.

Chapter 2

Design

2.1 Physical Diagram



Figure 2.1: Schematic of the Mechanical Design



Figure 2.2: CAD Simulation of the Instrument



Figure 2.3: Different Views of CAD

In Figure 2.2, the mechanical design of this system consists of five main components:

- (a) **Stepper Motor**: The stepper motor is secured to the motor bracket using four screws. Considering the need for manual adjustments during the initial setup and later connection to the driver, the motor is positioned at a relatively high location on the bracket.
- (b) **Lead Screw Coupling**: The lead screw is connected to the motor via a flexible coupling, converting rotational motion into linear motion to drive the selection module.

- (c) **Strain Gauge**: The strain gauge is attached to the cantilever beam to detect its minute deformations, converting mechanical strain into voltage signals for further amplification and processing.
- (d) **Specially Designed Mechanical Cantilever**: A small sphere is integrally fabricated to the front end of the cantilever via 3D printing. The sphere comes into contact with the sample, causing the cantilever to bend.
- (e) **Sample Support Platform**: The platform supporting the sample is fixed using four supporting columns to ensure the sample remains stable during measurement.



Figure 2.4: Sectional View

Figure 2.4 is the sectional view of the entire instrument, and the following Figures 2.5, 2.6, and 2.7 are orthographic views.



Figure 2.5: Orthographic Views of the Cantilever



Figure 2.6: Orthographic Views of the Motor Set



Figure 2.7: Orthographic Views of the Sample Stage and Supporting Part

2.2 Block Diagram



Figure 2.8: Block Diagram

2.3 Block Design

2.3.1 Mechanical Module

The mechanical module consists of three main components: the stepper motor, the lead screw, and the cantilever. The system operates by converting rotational motion from the stepper motor into linear displacement through the lead screw, ultimately applying force via the cantilever to interact with the sample.

Stepper Motor and Screw Coupling

The stepper motor is secured to the motor bracket using four screws. Considering the need for manual adjustments during the initial setup and later connection to the driver, the motor is positioned at a relatively high location on the bracket. The lead screw is connected to the motor via a flexible coupling, converting rotational motion into linear motion to drive the selection module.

Requirements	Verification
The stepper motor must achieve a lin-	A. Program the motor to move 100 mi-
ear stepping resolution in the range of	crosteps.
$1.0\pm0.5~\mu{\rm m}$ per step when driven in	B. Use a high-resolution micrometer or
1/16 microstepping mode and coupled	laser displacement sensor to measure
with a lead screw of 2 mm pitch.	the actual displacement.
	C. Verify that the average displacement
	per step falls within the specified range.

Table 2.1: Stepper Motor Requirements and Verification Plan

Motor and Screw Calculations

We hope the combination of the stepper motor and screw can achieve a step size smaller than 1 micron. The standard step angle for a 5-phase motor is 0.72° , which is much smaller compared to the typical 1.8° step angle of a 4-phase motor available in the market. Furthermore, we will use a motor driver to implement 10x microstepping. Finally, the motor will be combined with a lead screw with a 2mm lead. The step size for each step is calculated as follows:

$$\text{Step} = \frac{\text{Screw Lead}}{\left(\frac{1 \text{ rev}}{\text{Step angle}} \times \text{Subdivision}\right)} = \frac{1 \text{ mm}}{\left(\frac{360^{\circ}}{0.72^{\circ}} \times 10\right)} = 0.2 \ \mu m$$

Specially Designed Cantilever

A small sphere is integrally fabricated to the front end of the specially designed cantilever via 3D printing. The sphere comes into contact with the sample, applying force to the sample and causing the cantilever to bend.

Requirements	Verification		
1. The cantilever beam must have an	A. Apply known micro-masses (10 g) to		
effective spring constant k in the range	the cantilever tip.		
of 10–15 times larger than that of the	B. Measure the tip deflection using a		
material under room temperature and	laser displacement sensor.		
quasi-static loading conditions.	C. Repeat for multiple weights and av-		
	erage results. Confirm that the stiffness		
	is within the specified range.		
2. The cantilever beam must exhibit a	A. Apply a known force via standard		
tip deflection of at least 0.1 mm under	weights (10 g) .		
an applied force in the range of 0.1 N,	B. Measure the tip deflection using a		
to ensure a surface strain of at least $5\times$	laser displacement sensor.		
10^{-4} , detectable by a strain gauge with	C. Verify that the strain falls within the		
a sensitivity of $2.0 \pm 1\%$.	specified range.		

Table 2.2 :	Cantilever	Beam	Requirements	and	Verification	Plan
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Cantilever Design Calculations

The spring constant of the cantilever should be much larger than that of the sample.

$$k_c \gg k_s$$

Where k_c represents the spring constant of cantilever, and k_m represents the spring constant of the sample. This is to ensure that the deformation of the cantilever is mainly dominated by the deformation of the measured materials.

$$k_s = \frac{10^5 \times 1.96 \times 10^{-5}}{0.02} = 98 \text{ N/m}$$

The spring constant of the cantilever should be 10 times larger than $k_{s,min}$. The following table contains the parameters designed for the cantilever.

Table 2.3: Different Cantilever Design Parameters

Dimension (mm)	Length, l	Width, w	Thickness, t	Diameter, d
Cantilever 1	50	10	3	5
Cantilever 2	40	10	3	10
Cantilever 3	30	10	5	5

The cantilever will be fabricated by 3D printing, using PLA as material. The PLA has an elastic modulus of about 2.5 GPa [1].

$$k_{c,1} = \frac{E_c w t^3}{4l^3} = \frac{2.5 \times 10^9 \times (0.010 \times 0.003)^3}{4 \times (0.05)^3} = 1350 \text{ N/m}$$

$$k_{c,2} = \frac{E_c w t^3}{4l^3} = \frac{2.5 \times 10^9 \times (0.015 \times 0.003)^3}{4 \times (0.03)^3} = 9365 \text{ N/m}$$

Assuming a minimum detectable resistance change of 0.1%, we have:

$$\frac{\Delta R}{R} \ge 0.001$$

Given a gauge factor (GF) of 2.0, the minimum required strain is:

$$\varepsilon = \frac{\Delta R/R}{\mathrm{GF}} = \frac{0.001}{2.0} = 5 \times 10^{-4}$$

Assuming the strain gauge is bonded to the surface of the cantilever beam and experiences the same strain as the cantilever, the maximum strain typically occurs at the fixed end of the beam. Under the assumption of small deflection, the maximum surface strain at the beam root can be calculated using the following equation:

$$\varepsilon = \frac{3\delta t}{2L^2}$$

Given the required minimum strain of

$$\varepsilon \ge 5 \times 10^{-4}$$

we can rearrange the equation to calculate the minimum required tip deflection δ :

$$\delta \ge \frac{2\varepsilon L^2}{3t}$$

Plug in the parameters of Cantilever 2, it indicated that the vertical deflection of the cantilever should be 178 μm

2.3.2 Electrical Module (analog part)

- Functionality: The Wheatstone bridge is used to measure the unknown electrical resistance of the gauge, a Wheatstone bridge is developed using three 220 Ω resistor. the output signal is processed through an INA125 amplifier to improve the signal-to-noise ratio. The output of the amplifier is transmitted to ADC for digital processing and storage.
- **Requirement 1:** When the strain gauge is not bent, the resistance is 220 Ω , so under normal conditions, the Wheatstone bridge is balanced. If the strain gauge is bent, The magnitude of V_g reflects the change in R_x (the resistance variation of the strain gauge)



Figure 2.9: Schematic of the Wheatstone bridge

2.3.3 Analog to Digital Converter and Programmable Gain Amplifier

The HX711 is a precision 24-bit analog-to-digital converter (ADC) designed specifically for weighing scales and industrial control applications. The output signal is connected to the HX711 to generate the digital data flow. Extra capacitors are added at the analog input node to reduce voltage ripple and ensure isolation



Figure 2.10: Schematic Overview



Figure 2.11: PCB layout

The HX711 layout used in this study is based on Adafruit's open-source design [2].

2.3.4 Embedded Control Module

The Embedded Control Module is responsible for direct motor control, strain gauge data acquisition, and communication with the upper-level application software via UART. We use STM32F103C8T6 minimum system board as the controller, and the pin assignment and connection is described in the table and figure below:

Pin	Function	Description
PB6	TIM4_CH1 (PUL+)	PWM output to control stepper motor pulse signal
PB5	DIR+	Digital output for stepper motor direction control
PB10	HX711 DOUT	Receives strain gauge data from HX711
PB11	HX711 SCK	Clock signal to HX711 (PD_SCK)
PA9	UART TXD	Sends data to PC via CH340 USB-UART
PA10	UART RXD	Receives commands from PC via CH340 USB-UART
PB0	$SW2 (Move_Up)$	Button input to move motor upward
PB1	SW1 (Move_Down)	Button input to move motor downward
PA0	Red LED (System)	Turns on to indicate system error
PA1	Yellow LED (Status)	Turns on when cantilever contacts sample

Table 2.4: STM32 Pin Assignment Summary



Figure 2.12: Schematic for STM32 Control System

The control system communicates with the host PC via a serial interface. Upon receiving a START command, the stepper motor initiates forward motion to lower the cantilever, while the HX711 module begins sampling strain gauge data and transmitting it over UART. Contact with the material is determined by detecting a significant change in strain, with noise filtering applied. Once contact is detected, the system issues a fixed number of pulses to further displace the cantilever. The motor then reverses direction and continues moving until the strain signal remains stable for a defined duration, indicating separation. During the contact phase—regardless of motor direction—the measurement status LED (PA1) is illuminated. If an error is detected at any point, the system status LED (PA0) is activated. Prior to the start of measurement, PB0 and PB1 buttons can be used to manually control motor direction for cantilever positioning. The logic of the system is designed as a finite state machine (FSM), which has six states, as outlined below:

State	Actions
IDLE	Wait for START command from host PC; User can manually
	control motor using PB0/PB1 buttons; PA0 and PA1 LEDs
	are off; HX711 is idle.
MOVING_DOWN	Motor moves forward to press cantilever; HX711 starts sam-
	pling and transmits data via UART; Monitor strain signal for
	contact detection.
CONTACT_DETECTED	Yellow LED (PA1) is turned on; System continues to apply
	pressure by sending a fixed number of pulses; Continue trans-
	mitting strain data.
MOVING_UP	Motor reverses direction; System keeps reading strain data;
	When signal is stable (no change for a threshold duration),
	stop motor.
FINISHED	Stop motor and data transmission; Turn off yellow LED
	(PA1); Prepare to return to IDLE state.
ERROR	Stop all activities; Turn on red LED (PA0); Await reset or
	power cycle to return to IDLE.

Table 2.5: Control System FSM State Actions



Figure 2.13: Control System FSM

Motor Control Module: Timer-Based Stepper Control via GPIO

This module controls the stepper motor through the 5DM542C driver using STM32 GPIO pins. The pulse signal for step control is generated via TIM4, while direction and enable signals are handled via dedicated pins. This enables precise displacement control of the cantilever.

Requirement	Verification		
1. The system must generate pulse	A. Configure TIM4 to output pulses at		
signals at 500–2000 Hz with $\pm 2\%$ fre-	test frequencies (e.g., 500 Hz, 1000 Hz,		
quency accuracy to ensure consistent	2000 Hz).		
motor speed control.	B. Use oscilloscope to measure pulse		
	frequency and compare with expected		
	values.		
2. Direction change must take effect	A. Send direction switch command		
within 50 ms after command reception.	from PC.		
	B. Use oscilloscope to monitor DIR pin		
	and confirm transition within 50 ms.		

Table 2.6: Motor Control Module Requirements and Verification

Data Acquisition Module: Strain Gauge and HX711 Interface

The data acquisition module reads analog strain signals via the HX711 24-bit ADC. The STM32 retrieves digital data via GPIO and transmits it to the PC in real time. This module enables high-resolution force measurements during cantilever-material interaction.

Requirement	Verification
1. The system must sample strain data	A. Configure HX711 in 10 Hz mode.
at a rate of at least 10 Hz with a reso-	B. Log output values and validate up-
lution of at least 24 bits.	date rate.
	C. Confirm 24-bit resolution by analyz-
	ing raw digital output range.
2. The measured noise (peak-to-peak)	A. Place cantilever in unloaded static
in strain readings under static load	condition.
must be less than 10 LSB.	B. Record 100 data samples.
	C. Calculate peak-to-peak noise in
	LSB. Confirm it is less than 10.

Table 2.7: Data Acquisition Module Requirements and Verification

2.3.5 Application Software Module

The Application Software Module controls the overall measurement process through a state machine. It initializes the system, manages user interactions, controls motor movement, and processes force-displacement data. Final results are displayed in the GUI and can be saved to disk.



Top-Level Device Software Algorithm

Figure 2.14: Top-Level Device Software Algorithm

It relies on three key submodules to function effectively, as detailed below.

Serial Communication Module: QSerialPort and STM32 UART Transmission

The serial communication module establishes a bidirectional data channel between the STM32 microcontroller and the host computer using UART over a USB-to-serial connection. Leveraging the QSerialPort library on the PC side, it enables structured data exchange and real-time control signal transmission. This module ensures reliable data integrity and synchronization between user commands and system responses.

Requirement	Verification
1. The communication module must	A. Connect STM32 and PC via USB-
achieve bidirectional data transmission	to-UART.
at 96000 $\pm 5\%$ baud rate with a maxi-	B. Transmit a predefined 1KB data
mum data loss rate below 1% during a	packet from PC to STM32 and vice
60-second continuous test.	versa at 96000 baud.
	C. Record the number of successfully
	received bytes. Compute error rate.
	Confirm it is less than 1%.
2. The system must correctly parse and	A. Use QSerialPort to send
respond to structured command frames	valid/invalid 8-byte command frames
of 8 bytes, and update internal sta-	to STM32.
tus within 100 ms of receiving a valid	B. Monitor UART response time with
frame.	oscilloscope or logic analyzer.
	C. Confirm valid commands are parsed
	and system reacts (e.g., toggles GPIO)
	within 100 ms.

Table 2.8: Serial Communication Module Requirements and Verification

Data Processing Module: Force Calculation and Young's Modulus Estimation

The data processing module receives raw sensor data from the STM32, including strain gauge readings and displacement values. It computes the applied force using calibrated transformation equations and estimates the Young's modulus of the test material through a pre-trained machine learning model. This module serves as the analytical core of the system, translating low-level signals into meaningful mechanical properties.

Requirement	Verification
1. The force conversion algorithm must	A. Apply known calibrated weights to
yield force values with less than $\pm 10\%$	sensor.
error when compared against standard	B. Record strain gauge voltage and
weights.	compute force using algorithm.
	C. Compare computed force to ground
	truth. Verify relative error $< 5\%$.
2. The Young's modulus estimation	A. Run tests on three calibration ma-
model must produce results within	terials with known Young's modulus.
$\pm 10\%$ of the known reference values for	B. Capture force-displacement curve
at least 3 different materials.	and feed into ML model.
	C. Compare output modulus with
	known values. Ensure all deviations
	less than 10% .

Table 2.9: Data Processing Module Requirements and Verification

User Interface Module: Qt-Based GUI for System Control and Visualization

Our interface is developed using Qt and provides intuitive controls for motor movement, parameter configuration, and data visualization. It displays real-time force-displacement plots and allows the user to initiate material testing procedures. Through this interface, users interact with the system efficiently, monitor results live, and export data for further analysis.

Requirement	Verification		
1. The GUI must refresh the force-	A. Simulate serial data input at 10 Hz		
displacement graph at a minimum rate	using a test script.		
of 10 Hz with less than 200 ms latency $$	B. Use a screen recording tool with		
between data arrival and display.	timestamp overlay to measure latency.		
	C. Confirm display is updated within		
	200 ms after each data point.		
2. The user must be able to control	A. Click each control on the GUI.		
motor power and direction through the	B. Use a serial monitor to observe out-		
GUI, with correct serial commands sent	going command format.		
upon each interaction.	C. Verify commands match specifica-		
	tion and motor responds accordingly.		
3. The user must be able to save the	A. Click the "Save" button after gener-		
data of the F-Z curves after clicking	ating an F-Z curve.		
save and get the result of the elastic	B. Check the file system for a cor-		
modulus calculated from current curve	rectly named output file containing		
after clicking calculate.	time-stamped force and displacement		
	data.		
	C. Click the "Calculate" button and		
	verify that a Young's modulus value is		
	displayed, matching the result from an		
	independent offline analysis within 5%		
	error.		

Table 2.10: User Interface Module Requirements and Verification

2.4 Tolerance and Risk Analysis

2.4.1 Tolerance Analysis

Mechanical Design



Figure 2.15: Finite Element Analysis. a) strain distribution. b) stress distribution. c) Displacement distribution. d) strain distribution (original model).

The simulation of the cantilever finite element analysis is conducted under a vertical force of 0.1 N. The results indicate that the maximum strain occurs at the fixed end of the beam, with a value of 1.376×10^{-4} . The maximum deflection is 0.057 mm, and the safety factor is 15.

The printing accuracy of the cantilever will directly affect its dimensions, such as the beam's length, width, and thickness. This will, in turn, affect its mechanical properties, such as stiffness and sensitivity to deflection under force. Given that the printer's tolerance is ± 0.08 mm, it will lead to slight variations in the behavior of the beam. However, this could still be within acceptable limits depending on the precision required for the force measurement.

The combination of the stepper motor and lead screw achieves a positional accuracy of 0.01mm, ensuring precise positioning of the tool or sample. With a repeatability of ± 0.001 mm, the system can consistently perform the same action with minimal error. However, there is a lost motion of 0.003mm, which introduces small errors during the transmission process, potentially affecting the consistency of force application or displacement.

ADC HX711

Parameter	Conditions and Description	Min	Typ	Max	Unit
Full-Scale Differential Input Range	V(inp) - V(inn)		± 0.5 (AVDD/GAIN)		V
Effective Number-of-Bits (1)	Gain = 128, Rate = 10Hz		19.7		Bits
Noise-Free Bits (2)	Gain = 128, Rate = 10Hz		17.3		Bits
Integral Nonlinearity (INL)	Full-scale ratio		± 0.001		% of FSR
Common Mode Voltage Range		AGND + 1.2		AVDD - 1.3	V
Output Data Rate	Internal Oscillator, $RATE = 0$	10			Hz
	Internal Oscillator, $RATE = DVDD$		80		
	External Clock or Crystal, $RATE = 0$		$f_{clk}/1,105,920$		
	External Clock or Crystal, RATE = DVDD		$f_{clk}/138,240$		
Output Data Format	Binary Code	800000		7FFFFF	HEX
Output Settling Time (3)	RATE = 0		400		ms
	RATE = DVDD		50		
Input Offset	Gain = 128		0.1		mV
	Gain = 64		0.2		mV
Input Noise	Gain = 128, RATE = 0		50		nV(rms)
	Gain = 128, RATE = DVDD		90		nV(rms)
Temperature Coefficient	Input Offset Drift (Gain = 128)		± 12		nV/°C
	Gain Drift (Gain $= 128$)		± 7		ppm/°C
Common Mode Rejection Ratio	Gain = 128, RATE = 0		100		dB
Power Supply Rejection Ratio	Gain = 128, RATE = 0		100		dB
Output Reference Voltage (V_{BG})			1.25		V
External Clock or Crystal Frequency		1	11.0592	20	MHz
Power Supply Voltage	DVDD	2.6		5.5	V
	AVDD, VSUP	2.6		5.5	V
Analog Power Supply Current	Normal Operation		1500		μA
	Power Down		0.5		μA
Digital Power Supply Current	Normal Operation		100		μΑ
	Power Down		0.2		μA

$$\begin{split} \text{Gain} &= 128\\ V_{\text{ref}} &= 3.3\,\text{V}\\ \text{Input}_{\text{allow}} &= \frac{V_{\text{ref}}}{\text{Gain}} = \frac{3.3\,\text{V}}{128} \approx 25.78\,\text{mV}\\ 19\text{-bit resolution} &= \frac{\text{Input}_{\text{allow}}}{2^{19}} \approx \frac{25.78\,\text{mV}}{524288} \approx 0.049\,\mu\text{V} \end{split}$$

Wheatstone bridge noise simulation @300K



Figure 2.16: noise simulation at 300K

the thermal noise for Wheatstone bridge is 2.6nV, below the detectable range of the ADC, therefore the thermal noise will not largely affect the circuit output.

2.4.2 Risk Analysis

• Mechanical components: Mechanical components such as the motor, lead screw, and bearings may experience wear, which could affect the system's performance. The accumulation of wear may lead to increased backlash and decreased repeatability. Besides, changes in temperature, humidity, or vibrations can affect the mechanical parts of the system. For example, thermal expansion could alter the geometry of the lead screw or cantilever beam, leading to small changes in force application.

Regular calibration of the system will help compensate for small mechanical deviations and lost motion. Using high-precision components and low-backlash lead screws can reduce the effects of mechanical inaccuracies. The instrument will be maintained in the ambient environment to Ensure stable environmental conditions, which can help minimize external influences on the system.

• Digital system The QSerialPort block is an important yet sensitive part of the system. If there are issues like data loss, delays, or errors, the instrument will fail to provide accurate results. The QSerialPort must support baud rates matching the STM32's UART settings (e.g., 115200 bps or higher) to ensure that both command and sensor data are transmitted in real-time without significant delay. The acceptable tolerance for data loss or packet errors should be minimal (e.g., less than 0.5% packet loss per transmission). The communication latency between the Qt interface and STM32 must be low to maintain real-time interaction with the motor and accurate sensor readings. A tolerance of less than 10 milliseconds delay is acceptable.

Chapter 3

Cost Analysis

Name	Model	Price (RMB)
Optical Breadboard	300x300x13 M6	252
Strain Gage	350-3AA/120, 120-3AA/1K	30
HX711	/	4
Stepping Motor & Screw	28*32 0601/0802	495
Stage	100–200mm	
Stepper Motor Driver	5DM542C	340
STM32	STM32F103C8T6	34
ADALM1000	/	/
Aluminum Profile	2020L-1.5 (1m)	10.9
3-way Right Angle Connec-	2020*4	6.4
tor		
TOTAL		1168.3

Table 3.1: Bill of Materials for Mechanical and Electronic Components

Chapter 4

Schedule

Weelr	Teal	Deenengihiliter
week	Task	Responsibility
2/24/25	Discuss design requirements with professor	All
	Finalize schematic diagram of mechanical system	Tianyu Fu
3/3/25	Completed RFA and team contract	All
	Select and purchase key mechanical components	All
	Complete detailed CAD model of motor support struc-	Tianyu Fu
2/10/95	ture, screw stage, cantilever support and sample holder	
3/10/25	platform	
	Conduct experiments with the strain gauge and design	Ziyi Lin
	the Wheatstone bridge circuit	
	Explore the software architecture and draft the system	Kongning Lai &
	interface design	Yunzhi Lu
	Complete the PCB design assignment	All
	Compose the proposal	All
	Design cantilever geometries optimized for 3D printing	Tianyu Fu
3/17/25	Begin 3D printing of initial cantilever prototypes	Tianyu Fu
	Develop submodules of the control system	Kongning Lai &
		Yunzhi Lu

Table 4.1: Project Schedule and Task Allocation (Part 1)

Week	Task	Responsibility
	Assemble screw stage and cantilever support	Tianyu Fu
	Begin calibration tests for cantilever deflection (strain)	All
3/94/95	and force using a balance	
0/24/20	Use buttons to control GPIO output of PWM pulse and	Kongning Lai
	DIR signals	
	Use serial commands to control GPIO output of PWM	Kongning Lai
	pulse and DIR signals	
	Improve the interface and start connecting serial ports	Yunzhi Lu
	Test the stepper motor driver voltage/current	All
3/31/25	Assemble the motor mount and sample holder base	Tianyu Fu
	Connect stepper motor and driver for initial testing	Ziyi Lin
	Test linear motion of the cantilever mechanism	Ziyi Lin
	Connect strain gauge, HX711, and STM32 microcon-	Ziyi Lin &
	troller	Kongning Lai
	Test ADC conversion and data reading functionality	Ziyi Lin
	Implement serial communication between STM32 and	Yunzhi Lu
	the Qt interface	
	Implement the elastic modulus estimation algorithm in	Yunzhi Lu &
4/7/05	Python Difference in the second secon	Kongning Lai
4/7/25	Refine motion test for the cantilever stage	Ziyi Lin
4/14/05	Write the design document	All
4/14/25	a balance	Ziyi Lin
	Implement data transfer between STM32 and QT, along	Yunzhi Lu
	with real-time curves plotting	
4/21/25	Fine-tune alignment and motion control of the screw	Tianyu Fu
	stage	
	Integrate machine learning methods into the elastic	Kongning Lai &
	modulus estimation algorithm	Yunzhi Lu
4/28/25	Optimize cantilever design (geometry, stiffness, mate-	Tianyu Fu
	rial)	
	Integrate Python scripts and models into the QT frame-	Yunzhi Lu
	work	
	Integrate mechanical, electrical, and software modules	All
	into system	4.11
5/5/25	Conduct experiments on zero shift and balance resis-	All
F /10 /0F		A 11
5/12/25	Calibrate cantilever using known weights or displace-	All
F /10 /0F	ment	A 11
5/19/25	Document test results and apply final design refinements	All
5/26/25	Write final report	
	Prepare for team rehearsals and final project presenta-	All
	tion	

Table 4.2: Project Schedule and Task Allocation (Part 2)

Chapter 5

Ethics and Safety

Our project has several potential safety concerns and ethics considerations. First, we are using a 9V rechargeable battery, which could lead to short circuits, potentially leading to fire, or injury. Additionally, the strain gauge we are using has a voltage tolerance of approximately 10V, making it possible for electrical breakdown, which could directly cause a short circuit. To solve this issue, we will incorporate protective resistors in the circuit design and ensure that at least two people are present during each experiment for safety supervision.

Another safety concern involves our use of 3D printing technology to construct the cantilever beam. The printer nozzle operates at high temperatures, with the hot end reaching up to 300°C, posing a risk of burns. To prevent unnecessary injuries, we will wear protective gloves when handling the 3D printer and ensure careful operation to avoid direct contact with the heated components.

Additionally, most plastics release harmful gases when burned, and 3D printing is no exception. In particular, when using ABS and other engineering plastics, high temperatures may lead to the emission of xylene and other toxic substances. To mitigate the risks associated with hazardous emissions during 3D printing, we will wear protective masks and ensure proper ventilation in the workspace.

Last, the mechanical components will also be designed with safety in mind, following guidelines provided by the Occupational Safety and Health Administration (OSHA) and ISO 12100 for the safe design of machinery. This project adheres to various ethical codes, including those outlined by the American Society of Mechanical Engineers (ASME) and Institute of Electrical and Electronics Engineers (IEEE). These ethical codes emphasize transparency, safety, and the responsibility to ensure that engineering practices are conducted with the welfare of society and the environment in mind. Additionally, the project will reference ISO 13485 standards for medical device design, ensuring that safety, quality, and ethical considerations are incorporated into the final product.

References

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- [2] Adafruit, "Adafruit-hx711-24-bit-adc-pcb: Pcb files for the adafruit hx711 24bit adc," https://github.com/adafruit/Adafruit-HX711-24-bit-ADC-PCB/, 2024, accessed: 2025-04-14.