A MICRO-PENETROMETER FOR SNOW AND SOIL STRUCTURAL ANALYSIS

Xing Shen, Chenghao Mo
Zheyan Wu, Chenxian Meng

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1 Introduction

1.1 Problem and Solution Overview

In various fields such as agricultural production, archaeology, and disaster warning, the analysis of soil (sand, snow) is particularly important. The use of mechanical penetration can detect the bonding forces of soil (sand, snow) at different depths, and serve for subsequent data analysis. The existing analytical instruments have many problems, such as too large volume, limited application scenarios, insufficient operation convenience, and insufficient accuracy. [1, 2] We hope to have a portable, simple to operate, intuitive results, and adaptable to different scenarios for people to use.

We envisioned designing a machine that could drive a rod with a force sensor into soil (sand, snow) and record the force it received in real time. After integrating the data records, the penetration force characteristics of the sample at different depths could be visually reflected by color. Furthermore, this machine could also achieve multiple sampling and analysis of small-scale ground samples without moving the device by changing the horizontal position of the rod.

The specific implementation method is as follows: The controller controls the movement of the mechanical structure. During the movement, the data collected by the force sensor can be transmitted to the computer in real time by Bluetooth, and stored in the computer. The data analysis and result presentation can be carried out through the supporting software on the computer. After a single sampling, the rod will be reset to the initial height. If necessary, the horizontal position of the rod will be changed and the sample will be taken again. In addition, in the case of Bluetooth connection, users can also control the machine by using Bluetooth devices.

Our solution is to design an mechanical product which can test the force when drugging into the soil with pressure sensor and move xyz axis automatically. Also, we need to design the control parts to control the motor movement and read the transient data of sensor. The data can be displayed on computer with Bluetooth block.

1.2 Visual Aid

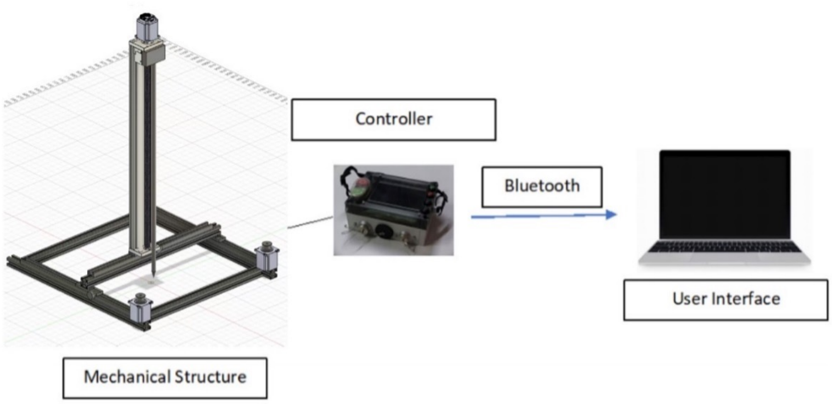

Figure 1: Visual Aid

1.3 Highlevel-List

1. The total mass of the machine shall not exceed 10KG.
2. The accuracy of data acquisition shall not exceed 0.1mm.
3. The rod with a powerful sensor shall have a horizontal movement range of at least 40cm*40cm.
4. The detector is capable of penetrating soil with a compactness of 2 MPa.

2 Design

Our Penetrometer Mainly consists of three systems, Mechanical System, Data Processing System and Control System. The Mechanical System includes the mechanical rod and force sensor, responsible for penetrating soil or snow and measuring the force encountered. The Data processing system ensures the data transfer, form force sensor to micro controller and form micro controller to the computer. The Control System includes the user interface on the computer and a STM32 MicroController. Below is our block diagram of the Penetrometer

2.1 Block Diagram

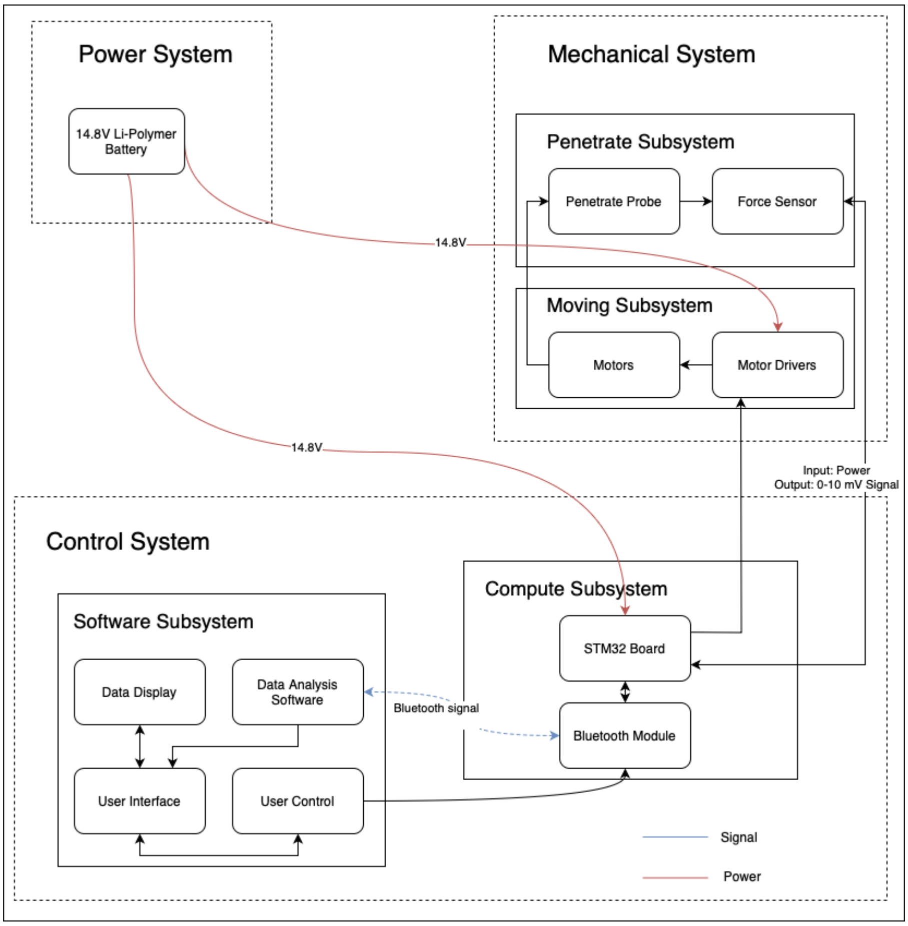

Figure 2: Block Diagram

2.2 Mechanical Description

The mechanical structure we designed allows the probe to move within a horizontal range of approximately 50mm * 50mm, and can overcome a pressure of approximately 2MPa. In addition, the screws on the base can keep the instrument level on uneven ground. The mechanical sensor is placed at the tip of the detection rod.

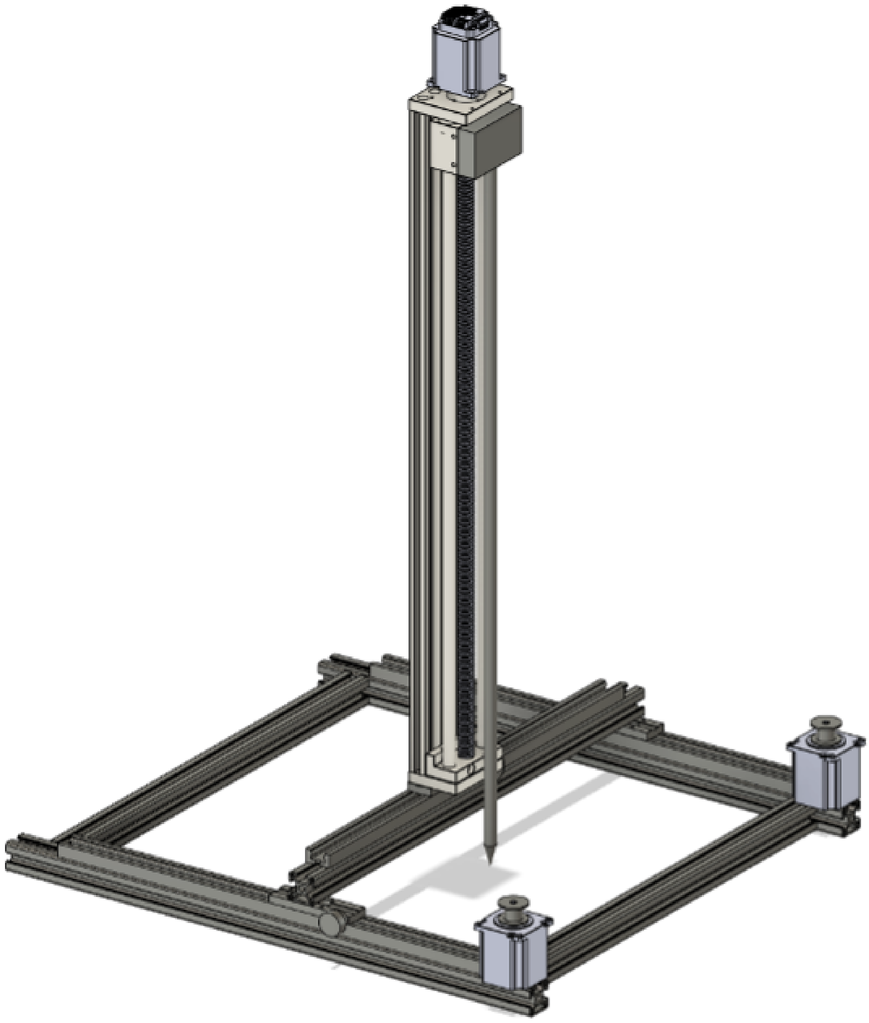

Figure 3: Mechanical Description

2.3 Penetrate Subsystem

The penetrate subsystem is composed of a penetrate probe and a force sensor, the force sensor should sending the magnitude of the force and send it to the micro controller.

2.3.1 Force Sensor

Input: : Physical force
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The force sensor has a built-in Force Sensitive Resistor (FSR) whose resistance varies according to the applied pressure. The force sensor here, with a 0-300N range and a sensitivity resolution of 1.0±10% mV/V, is a strain gauge-based transducer designed to convert applied force into a measurable electrical signal. When interfaced with an STM32F407IGT6 microcontroller, the sensor's excitation wires are connected to a stable 5V supply and ground, while the signal wires are linked to the microcontroller's ADC inputs to facilitate precise data acquisition. This setup enables the conversion of the mechanical force into digital values, which the STM32 controller can process and interpret. Calibration is imperative to correlate the ADC readings to actual force measurements accurately, considering the sensor's specified sensitivity and ensuring that the 10% tolerance is accounted for in the measurement system. This integration not only provides a reliable method to measure forces within its capacity but also allows for real-time monitoring and analysis when coupled with the microcontroller's computational capabilities, making it a suitable choice for a wide range of applications demanding force quantification.

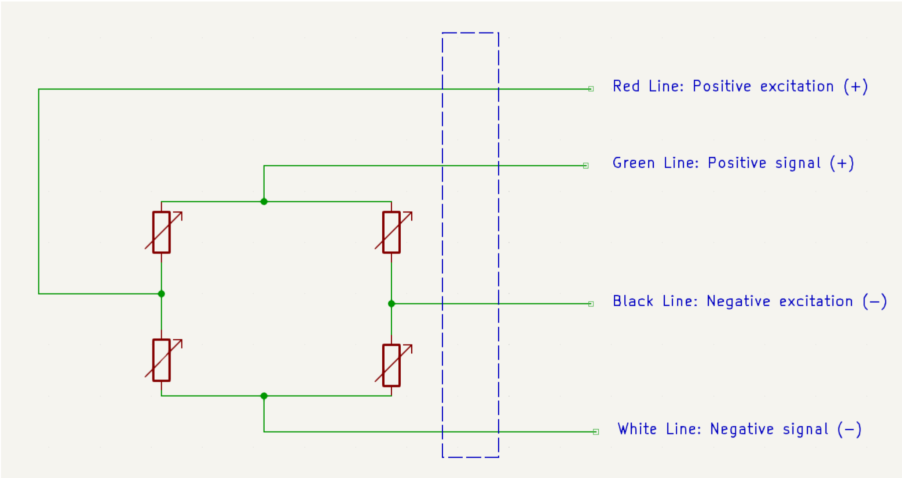


Figure 4: Force Sensor Schematic Diagram

Requirement	**Verification Procedure**
The force sensor must display pressure levels on a screen, which vary with the applied force. The sensor must accurately measure pressure corresponding to the force applied by different displacements of an elastic spring with an accuracy of 10%.	1. Place block between Force Sensor and elastic spring to measure displacement vs. force. Measure the voltage at each level of force and then plot Force vs. Voltage with data obtained and testify the trend of the plotting. 2. Put standard weights of different weights on the force sensor and check the force read from the sensor F with standard value (S). Use the formula for Error Rate, And the Error Rate should be less than 10%. $$\text{Error Rate} = \left\lvert \frac{F-S}{S} \right\rvert \times 100\%$$

Table 1: Force Sensor Requirements and Verification

2.4 Moving Subsystem

2.4.1 Motor Unit

High-performance stepper motor driver (ATK-PD5050S)
The ATK-PD5050S module [3] is a versatile and rugged stepper motor driver that enables motors to dig down at a steady speed. The module operates from a 12 to 50V DC supply voltage range and has an output current of up to 5.0A, effectively driving a two-phase hybrid stepper motor at a constant speed. It boasts cutting-edge features including high-resolution microstepping for detailed motion control, load-based power optimisation for energy savings, and a low-resonance chopper algorithm that minimises vibration for improved motion accuracy. Integrating the ATK- PD5050S with an STM32F407IGT6 microcontroller typically involves connecting the drive's power input to the microcontroller's controlled voltage output, aligning the motor connections with the drive's terminals, and establishing communication for pulse, direction, and enable functions via optically isolated control signals. This integration will facilitate sophisticated motor control through the microcontroller's firmware, which generates PWM signals to control motor direction and to engage or disengage the motor as required by the application.

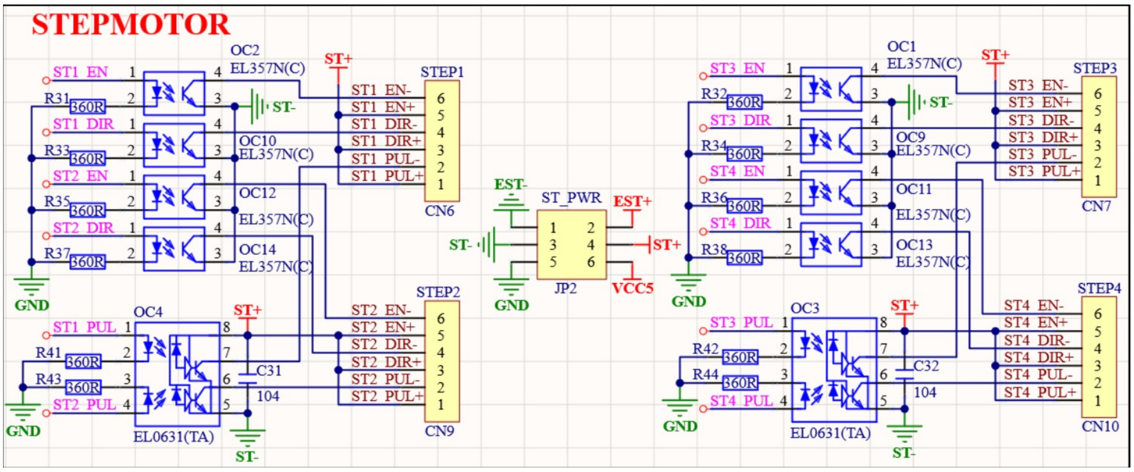


Figure 5: Motor Unit Schematic Diagram

Pin	Name	Description
ENA-	Enable negative	When the negative enable signal is effective, the internal logic signal is valid. When the signal is invalid, the internal logic is suspended, and the output is low impedance, high level, and the internal clock is stopped.
ENA+ (5V)	Enable positive (5V)	When the positive enable signal is effective, the internal logic signal is valid. When the signal is invalid, the internal clock is suspended, and the output is high impedance, high level.
DIR-	Direction negative	When the negative direction signal is effective, the internal logic determines the direction, and when the signal is invalid, the direction is determined externally.
DIR+ (5V)	Direction positive (5V)	When the positive direction signal is effective, the internal logic determines the direction.
PUL-	Pulse negative	When the negative pulse signal is effective, the internal logic is triggered, and when the signal is invalid, the external high level maintains the current state.
PUL+ (5V)	Pulse positive (5V)	When the positive pulse signal is effective, the internal logic is triggered, and the speed of the pulse is 200kHz.

Table 2: Motor Driver Pin Descriptions

ATK-PD5050S Interface	F407 Corresponding Interface
ENA-	PF15
ENA+	ST+
DIR-	PF14
DIR+	ST+
PUL-	PI5
PUL+	ST+

Table 3: Motor Driver Interface Pin Correspondences

Requirement	Verification Procedure
The motor unit will be able to control the rod at a velocity of 20 mm/s with error rate below 5%.	1. Attach a pen to the rod at the starting position on a piece of graph paper. 2. Program the motor to move the rod. Start the motor unit and mark the new position of the rod every 2 seconds. 3. After a set time period, stop the motor unit and measure the distance between each mark to calculate the displacement over 2-second intervals. 4. Use the formula $Speed = \frac{\Delta Time}{\Delta Distance}$ to calculate the speed for each interval. 5. Verify that the calculated speed is within ±5% of the target velocity. If the speed is outside this range, adjustments should be made and the test repeated.

Table 4: Motor Driver Requirements and Verification

2.5 Compute Unit

2.5.1 Microcontroller (ATK-DMF407)

Input: 5V(USB) or DC6V 24V(DC005), voltage signal from sensor, data from motor driver
Output: command to motor driver, data of force sensor to Bluetooth Module
The microcontroller (ATK-DMF407) [4] serves as the central hub for interfacing with the Bluetooth module (ATK-MW579), the force sensor (DYMH-106), and the motor unit (ATK-PD5050S). It connects to the Bluetooth module utilizing TX and RX pins for bi-directional data exchange, allowing for wireless communication with other devices using UART. The force sensor is linked to an analog GPIO pin on the microcontroller, enabling the measurement of variable voltages that correspond to physical forces applied to the sensor. This analog signal is then digitized by the microcontroller for processing. For the motor unit, the microcontroller uses digital GPIO pins to send control signals (enable, direction, and pulse) to the stepper motor driver, dictating the motor's operational state, direction, and speed. This intricate network of connections between the microcontroller and the various components facilitates a seamless integration, enabling the microcontroller to collect data, process inputs, and control outputs, thus forming the backbone of a sophisticated sensor and control system.

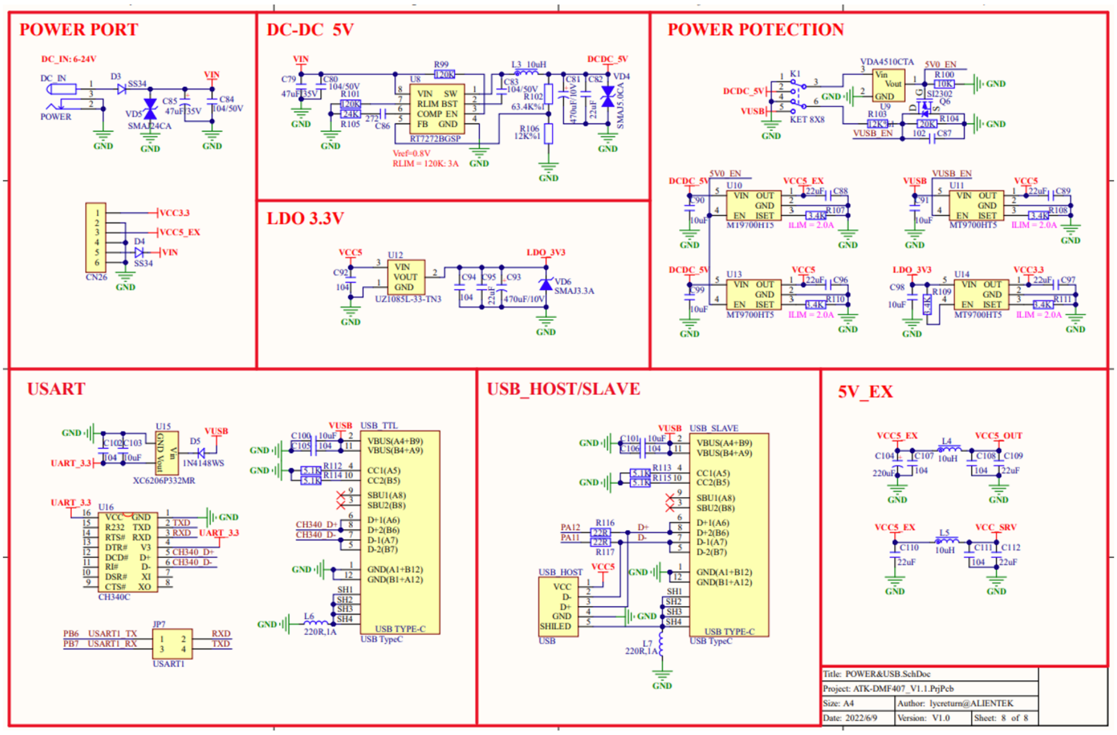


Figure 6: Micro Controller Schematic Diagram

Component Interface	ATK-MW579 Pin	ATK-PD5050S Interface	F407 Corresponding Interface
Power Supply (VCC)	VCC	-	5V
Ground (GND)	GND	-	GND
UART Transmit (TXD)	TXD	-	PB11
UART Receive (RXD)	RXD	-	PB10
Status Indicator	STA	-	PF6
Wake Up (WKUP)	WKUP	-	PC0
Enable Negative	-	ENA-	PF15
Enable Positive	-	ENA+	ST+ (Supply Voltage Positive)
Direction Negative	-	DIR-	PF14
Direction Positive	-	DIR+	ST+ (Supply Voltage Positive)
Pulse Negative	-	PUL-	PI5
Pulse Positive	-	PUL+	ST+ (Supply Voltage Positive)

Table 5: Microcontroller Pin Interface Mapping

Requirement	Verification Procedure
The microcontroller should handle processing with minimal delay, aiming for a maximum latency that is imperceptible to the user. In interactive applications, this latency should typically not exceed 100ms. They can both receive and transmit over SPI at speeds over 3Mbps.	1. Establish a connection between the STM32 microcontroller and a USB-to-SPI interface device, and interface it with a terminal program. 2. Initiate a timer and transmit a random data block of 0.30Mbit from the USB-to-SPI interface directly to the STM32 unit. 3. Return the data to the sender, this time utilizing the STM32's SPI capabilities for transmission. 4. Halt the timer upon data reception and confirm the integrity of the data against the original, ensuring the round-trip time does not surpass 100 milliseconds.

Table 6: Microcontroller Requirements and Verification

2.5.2 Bluetooth Module (ATK-MW579)

Input: 3.3V 5V power supply and pin connection with microcontroller
Output: data transmitted to host device (Bluetooth protocol)
The Bluetooth Module modulates 1Mbps enhanced data rate with complete 2.4GHz radio [5].

Pin	Name	Description
1, 3, 9, 19, 20	GND	Ground
2	ANT	Antenna
4	SLEEP	Sleep Mode
5	WKUP	Wake Up, Active High
6	RELOAD	Reload Counter
7	RXD	UART Receive (RX) Pin
8	TXD	UART Transmit (TX) Pin
10	3V3	Power Supply (3.3V 5V)
11˜15, 18	NC	Not Connected
16	LINK	Connection Status Indicator (Active Low: Connection, Active High: No connection, Flashing: Transmitting)
17	RST	Reset (Active Low)

Table 7: Bluetooth Module Pin Description

Connection with STM32 dev board.

ATK-MW579 Pin	F407 Corresponding Interface
VCC	5V
GND	GND
TXD	PB11
RXD	PB10
STA	PF6
WKUP	PC0

Table 8: ATK-MW579 to F407 Interface Mapping

Requirement Description	Verification Procedure
Module must be properly initialized with UART settings for communication.	Verify the UART settings on the module match the system's requirements by sending AT commands and ensuring appropriate responses are received.
Module must be discoverable by the host device for connection establishment.	Perform a scan on the host device and verify that the ATK-MW579 is listed among the discoverable devices.
Module must be able to establish a Bluetooth connection with the host device.	Initiate a connection from the host to the module and verify successful connection establishment by checking the module's LINK pin or LED status.
Module must transmit data with integrity to the host device over an established Bluetooth connection.	1. Send a predefined data string from the module to the host and confirm receipt on the host side. Use a logic analyzer or software to capture and verify the transmitted data. 2. Compare the received data on the host device against the original string sent from the module to ensure data integrity.

Table 9: Bluetooth Module Requirements and Verification

2.6 Power System

Input: Li-Polymer Battery (14.8 V, 48 Wh)
Output:

1. DC6V 24V for Microcontroller (ATK-DMF407)
2. DC12 50V for High-performance stepper motor driver (ATK-PD5050S)

Our project's power system is centered around a highly efficient Li-Polymer Battery, which boasts a 14.8V, 48 Wh specification, designed to cater to the diverse energy needs of our setup. This battery adeptly provides a variable DC output range, offering 14.8V for the microcontroller (ATK-DMF407) , and it is within range of DC 12V to 50V for a high-performance stepper motor driver (ATK-PD5050S), ensuring both precision and power. Furthermore, critical components like the Bluetooth module and the force sensor derive their power indirectly through the microcontroller, showcasing our system's integrated approach to power distribution and management for optimal functionality and efficiency.

Requirement	Verification Procedure
Supply $\pm 14.8V \pm 5\%$ power for both Microcontroller and motor driver.	Use a multimeter to check if the voltage output are specified values $\pm 14.8V \pm 5\%$. And use an oscilloscope to check if the voltage signal is steady.

Table 10: Power System Requirements and Verification

2.7 Software Subsystem

Our Software subsystem mainly consists of 4 parts. Data Display, Data Analysis, User Interface and User Control. Users can use User Control to set parameters, such as the drilling depth, drilling positions and so on. The Data Analysis part will analysis the bluetooth signal sent by Bluetooth Module, then send it to the User Interface. The User Interface will display the position, the depth and the force values, and send a figure to Data Display, where a 3d figure will show on the computer screen. This is the flow chart for our software subsystem.

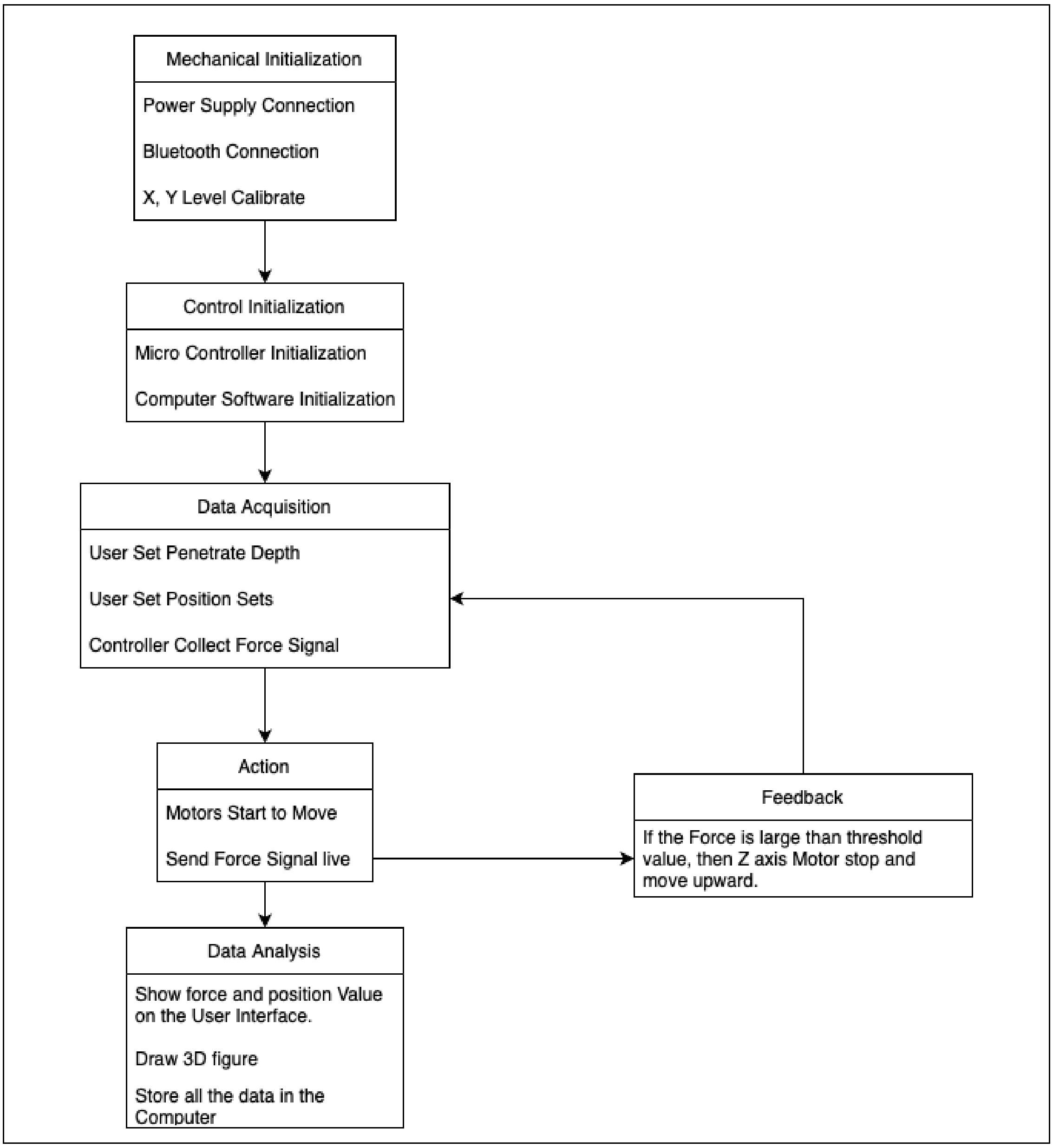


Figure 7: Software Subsystem Flow Chart

2.8 Calculation

2.8.1 Power Consumption

Battery Specifications:

1. Type: Lithium Polymer (Li-Poly)

2. Voltage: 14.8 V
3. Energy Capacity: 48 Watt-hours (Wh)
4. Battery Capacity: $\frac{48}{14.8} = 3.24Ah$

Load	Voltage	Current (Active Mode)
Microcontroller	+6V˜24V	+140mA
Bluetooth Module	+3.3V	+8.7mA
Motor Driver	+12V-50V	+0.75A
	Total	0.8987A

Table 11: Electrical Specifications

Drilling Operation Specifications:

1. Target Depth: 50 cm
2. Drilling Rate: 20 mm/s
3. Time to Drill One Hole: Approximately 25 seconds (0.00694 hours)

Power Consumption and Drilling Capacity: Each drilling operation consumes roughly 0.0924 Wh of the battery's energy. Based on the total energy capacity of 48 Wh, the system can perform approximately 500 drilling operations on a full charge. This estimate assumes constant current consumption as per the system's active mode specifications and includes the energy expenditure for the drilling process. For the experiment of going out to investigate the soil structure, the 500 boreholes of this equipment can meet our needs.

Important Considerations:

1. The number of holes drilled is contingent upon the current draw being consistent with the system's active mode consumption.
2. The efficiency of the drilling process and the hardness of the soil are variables that can impact the actual number of holes that can be drilled. Soil that is more compact or contains rocks may require more energy to drill.
3. Battery performance can degrade over time, and environmental factors like temperature can influence the effective capacity of the battery.

An analysis of theoretical calculations of power consumption for drilling operations shows that with an available lithium polymer battery with an energy capacity of 48 Wh and a calculated battery capacity of 3.24 Ah at 14.8 V, the system is capable of performing approximately 500 drilling operations before needing to be recharged, providing for the fulfilment of field expeditions. This calculation assumes a constant current consumption consistent with the specified activity pattern of the system, considering a total current consumption of all components of 0.8987 A. However, the efficiency of these operations is dependent on the homogeneity of the soil composition and the physical state of the battery, which may vary due to factors such as soil density and ambient temperature. Therefore, while the theoretical ability to perform 500 boreholes under optimal conditions provides a robust baseline for operational planning, actual performance may be biased by real-world variables and the inherent degradation of cell efficiency over time.

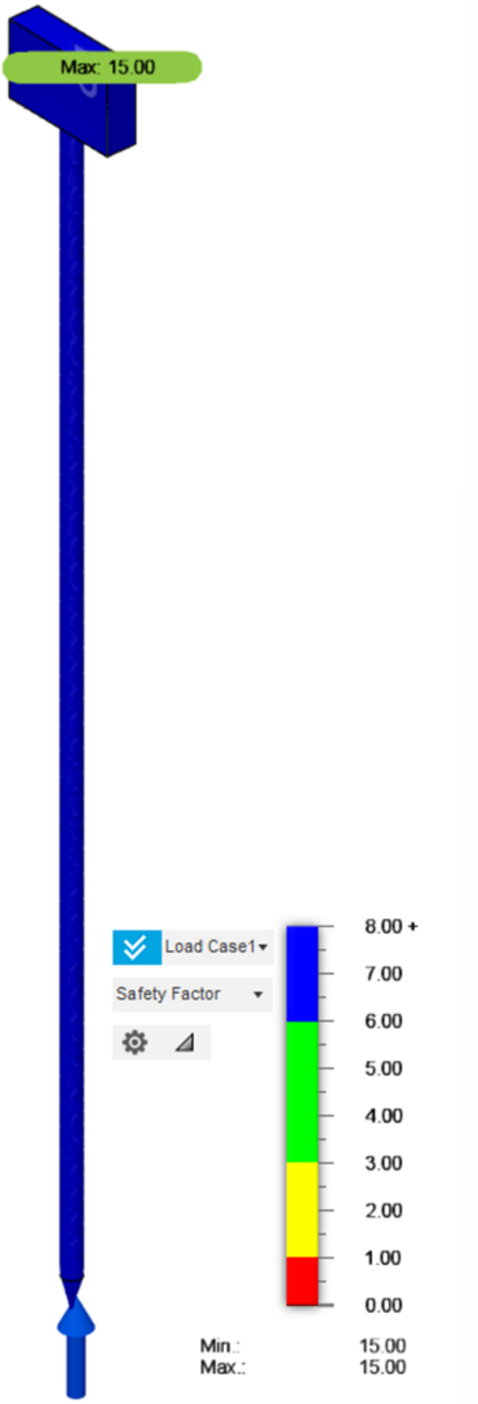
2.9 Tolerance Analysis

Due to the longer length of the detection rod we used and the greater force we experienced during using, we used simulation to calculate the safety factor of the rod when working in soil. The safety factor formula is:

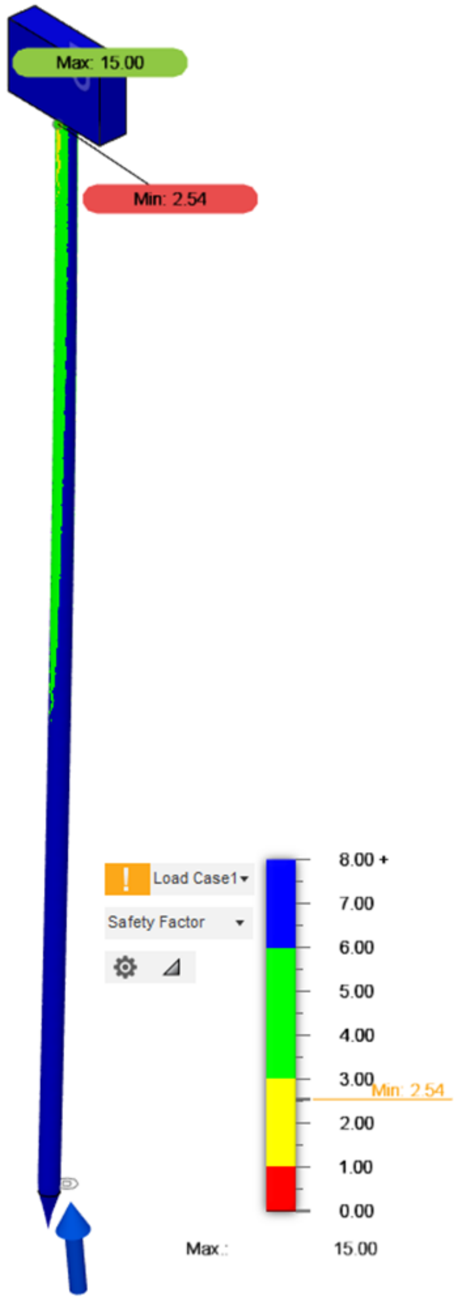
$$SF = \frac{UltimateLoad(Strength)}{AllowableLoad(Stress)} \tag{1}$$

Research has shown that the penetration pressure of soil is between 0.8MPa and 1.9MPa. We calculate based on the formula $F = P * \frac{\pi}{4}d^2$, and get the force acting on the detection rod is approximately 260N. So we set the conditions for the rod tip to be subjected to a pressure of 260N, as well as a forward and backward tilt of 5 ° and a lateral tilt of 5 °, and obtained four different results to simulate the force situation of the rod when encountering uneven ground. From the results obtained, it can be seen that the safety factors of the detection rods are all above 2.5, which is within an acceptable range.

In the figures, the legend on the side tells us that colors represent different safety factor values, with the blue part having the highest safety factor, indicating that this part is least likely to breakage.

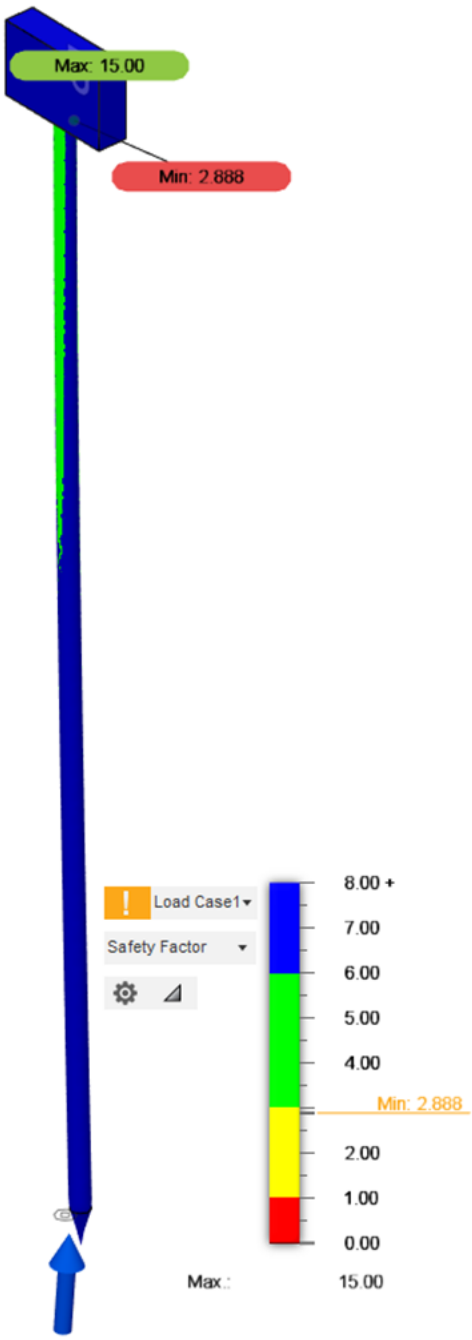


(a) Safety factor under 260N, tilt angle of 0°

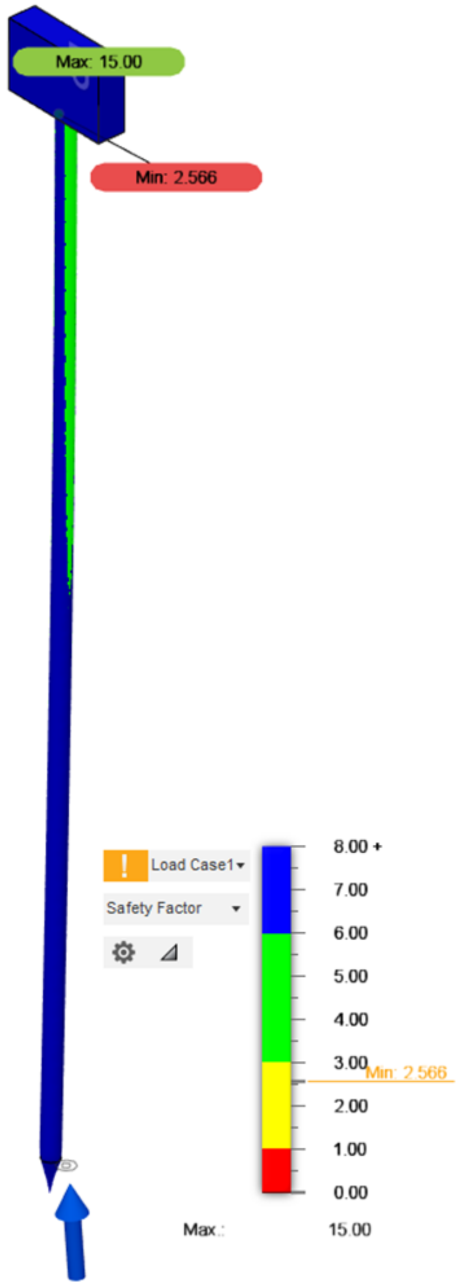


(b) Safety factor under 260N, tilt angle of 5° backward

Figure 8: Safety factors for 0° and 5° backward tilt angles.



(a) Safety factor under 260N, tilt angle of 5° forward



(b) Safety factor under 260N, tilt angle of 5° lateral

Figure 9: Safety factors for 5° forward and lateral tilt angles.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

Name[1]	**Hourly Rate**[1]	**Hours**[1]	**Total**[1]	**Total x2.5**[1]
Chenghao Mo[1]	$30[1]	200[1]	$6000[1]	$15000[1]
Xing Shen[1]	$30[1]	200[1]	$6000[1]	$15000[1]
Zheyan Wu[1]	$30[1]	200[1]	$6000[1]	$15000[1]
Chenxian Meng[1]	$30[1]	200[1]	$6000[1]	$15000[1]
Total[1]			$60000[1]	

Table 12: Labor Costs[1]

3.1.2 Parts

Description	Quantity	Manufacturer	Vendor	Cost/unit	Total cost
Li-Polymer Battery (14.8 V, 48 Wh)	1	Wei Zhen	Tao Bao	¥34.20	¥34.20
GGP Dual optical axis ball screw module guide rail with motor	1	Mei Ke Transmission	Tao Bao	¥310.00	¥310.00
57HB56L4/1.2Nm motor	2	Planetary Deceleration	Tao Bao	¥50.00	¥100.00
3030N1-Aluminum profile	4	YYDS	Tao Bao	¥24.00/m	¥56.00
3030ED-Aluminum profile	1	YYDS	Tao Bao	¥21.00/m	¥12.00
Manufacture service for Aluminum profile	4	YYDS	Tao Bao	¥1.00	¥4.00
3030 Corner code	10	YYDS	Tao Bao	¥1.20	¥12.00
Delivery fee for Aluminum profile	1	YYDS	Tao Bao	¥12.00	¥12.00
DYM-106 Micro pressure sensor	1	Ocean Sensor	Tao Bao	¥234.00	¥234.00
Bluetooth module	1	Zheng Dian Atom	Tao Bao	¥56.36	¥56.36
Stepper motor driver	3	Zheng Dian Atom	Tao Bao	¥114.86	¥344.58
Motor control development board	1	Zheng Dian Atom	Tao Bao	¥532.38	¥532.38
Plum blossom handle screw	4	Wu Xi Quality	Tao Bao	¥0.74	¥2.80
Large head screw	1	Guwan Ji	Tao Bao	¥7.82	¥7.82
Guide rail slide	3	Zhejiang Zhenhao	Tao Bao	¥30.00	¥90.00
Guide rail slide with lock	3	Zhejiang Zhenhao	Tao Bao	¥48.00	¥144.00
Belt pulley	4	AET Hardware	Tao Bao	¥9.00	¥36.00
Belt	2	Libose	Tao Bao	¥9.00	¥18.00
Total					**¥2006.14**

Table 13: Component Costs

3.1.3 Grand Total

Section	Total
Labor	$60000
Parts	¥2006.14
Grand Total	$60277.45

Table 14: Grand Total Costs (Labor + Parts)

3.2 Schedule

Table 15: Project Schedule and Task Allocation

Week	Task	Responsibility
1/22/2024	Project Selection Form (Mon)	All
	PCB Design Exercise (Fri)	All
	Team Contract (Fri)	All
2/26/2024	Request for Approval (Wed)	All
	Decide the function of the product and allocate the work	All
3/4/2024	Proposal Early due (Thur)	All
	Discussed with professor and decided basic parameters	Xing Shen
	Search for information about motors and sensors	Chenghao Mo
	Search for parts for aluminium profile and other mechanical parts	Zheyan Wu
	Study the CAD models for the whole structure	Chenxian Meng
3/11/2024	Proposal (Mon)	All
	Decide the control system with a micro control unit and PCB design	Xing Shen
	Select a specific force sensor and learn how to transmit the data to a computer	Chenghao Mo
	Design the structure and buy some mechanical parts	Zheyan Wu
	Buy ball screw module guide rail with motor and battery	Chenxian Meng
3/18/2024	Learn how to connect Bluetooth unit and force sensor to the micro control unit	Xing Shen
	Get the sensor and try to read the data in practice	Chenghao Mo
	Build up the first version of main structure	Zheyan Wu
	Build up the first version of main structure	Chenxian Meng
3/25/2024	Project Proposal Regrade (Tue)	All
	Design Document (Wed)	All
	Try to use the Bluetooth control in practice	Xing Shen
	Use the sensor the control system to read the data	Chenghao Mo
	Make adjustment of basic structure and design the probe	Zheyan Wu
	Test the real force in soil with sensor and estimate the range.	Chenxian Meng
4/1/2024	Teamwork Evaluation (Thur)	All
	Connect the control system with driver and motor and make adjustment	Xing Shen
	Use Bluetooth unit to connect sensor and read the data	Chenghao Mo
	Design the suitable probe with correct testing range	Zheyan Wu
		Continued on next page

Table 15 – continued from previous page

Week	Task	Responsibility
	3D printing the probe and test it in the soil	Chenxian Meng
4/8/2024	Individual Progress Report (Wed) Fix the problem the control the motor as desired Fix the problem about sensor transmitting and realize the function Design the rest xy aix about its automatic moving function Buy the belts, belts pulley and relevant connections	All Xing Shen Chenghao Mo Zheyan Wu Chenxian Meng
4/15/2024	Design Document Revision (Fri) Study the rest two axis of motor control Perfect the function of interaction function Assemble the rest part of xy axis Assemble the rest part of system with control system	All Xing Shen Chenghao Mo Zheyan Wu Chenxian Meng
4/22/2024	Connect all control system together and find problem Continue test the part of testing data and reading data Test the work process and find the problem Make adjustment of the structure	Xing Shen Chenghao Mo Zheyan Wu Chenxian Meng
4/29/2024	Fix the problems of control system Fix the problems of data reading process and presentation Complete the whole mechanical structure Make sure the physical work of the product	Xing Shen Chenghao Mo Zheyan Wu Chenxian Meng
5/6/2024	Main Mock Demo Final Report draft (Fri) Find the potential problems and fix them	All All All
5/13/2024	Final Demo Block Final Presentation Final Individual Design Report draft	All All All
5/20/2024	Final Individual Design Report (Tue) Functionality Demonstration Video (Tue) Final Report (Tue) Teamwork Evaluation II (Tue)	All All All All

4 Safety

There are several potential safety hazard with our project. First is in the moving subsystem. If we overcharge the Li battery, then it may be brought to an extreme high temperature or even explosion. In this case, we will use a timer to control the charge time of the Li battery, when the battery interface shows that it have been fully charged, then we should immediately stop the charging. Besides, after we shut done the machine, we should disconnect the battery with the motor and micro controller, in order to make these electronic device safe.

Besides, consider the working environment, our electronic device cannot working when it is raining, snowing, which may cause electronic device irreversible damage. For the temperature, our device is allowed to work on a large range of temperature, from $-20°C$ to $40°C$. Both high or low temperature may cause damage to the electronic devices.

Since there are several Al material in our device, its corners may cause injury to users, so we should make sure every sharp corner is rounded. Meanwhile, the probe is also in a sharp corn shape, so when we turn off the machine, we should make sure a protection cover is add to the probe.

Furthermore, all members of the team have completed the lab safety training before engaging with any lab work. The trainings completed include both general laboratory safety training and electrical safety training.

5 Ethical Issues

Our project follows IEEE codes [6] of ethics as following:

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.

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

5 To improve the understanding of technology; its appropriate application, and potential consequences.

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.

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

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.

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