A MICRO-PENETROMETER FOR SNOW AND SOIL STRUCTURAL ANALYSIS

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March 7, 2024

1 Introduction

1.1 Problem

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. We hope to have a portable, simple to operate, intuitive results, and adaptable to different scenarios for people to use.

1.2 Solution

We envisioned designing a machine that could drive a rod with a strong 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 will be recorded in the SD card of the machine, and can be transmitted to the computer in real time by Bluetooth. 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.

1.3 Visual Aid

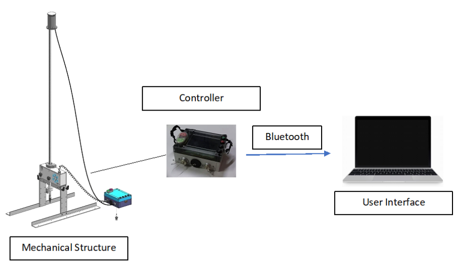

Figure 1: Visual Aid

1.4 Highlevel-List

1. The total mass of the machine shall not exceed 15KG.
2. The accuracy of data acquisition shall not exceed 10 microns.
3. The rod with a powerful sensor shall have a horizontal movement range of at least 20cm*20cm.

2 Design

2.1 Block Diagram

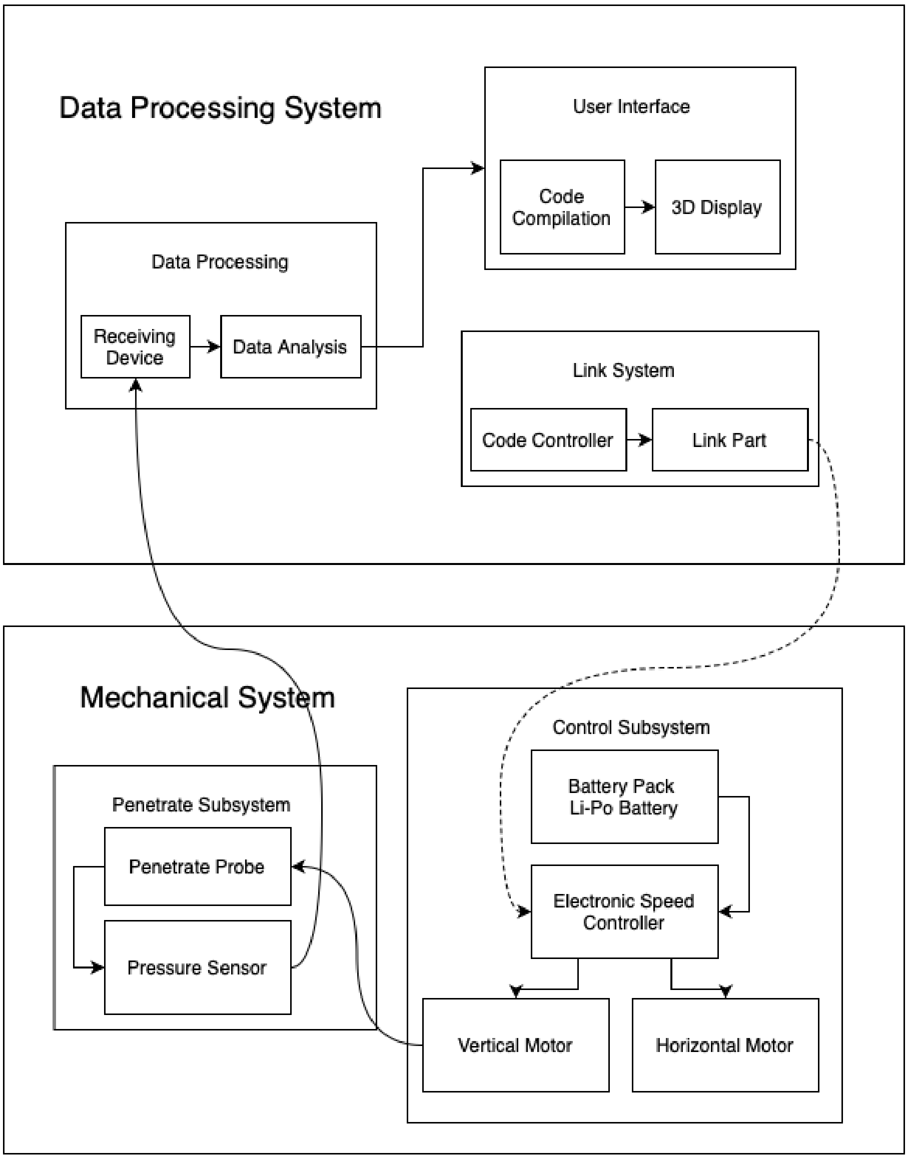

Figure 2: Block Diagram

2.2 Subsystem Overview

2.2.1 Penetrate Subsystem

It's a part of mechanical system because it includes the entity penetrate probe and pressure sensor. The function of them is to penetrate the snow or the soil and at the same time, measure the tip force. The probe and sensor are connected in a particular way. And the sensor provide the data of transient force so that it serves to the data processing and connects to the receiving device. As for the penetrate probe, the vertical motor drive it go down the snow or the soil at even speed, which is the reason why it connects to the control system.

2.2.2 Control Subsystem

First of all, the control subsystem cannot live without the battery. The battery provides the power to the electronic speed controller and the motors. the electronic speed controller aims to control the moving path, speed and time of the motor, which needs the codes and link part remotely. Then, we can use the speed controller to make the motors move in any way we want. The whole detector can measure whatever parts of the snow or soil as we desire to. It is how our product reaches automation.

2.2.3 User interface Subsystem

We are going to show the result of the relationship between the force and different displacement and the depth of the snow or the soil through 3D plot., which is the way of user interface. And we use code compilation to transfer the collected data to the plot.

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2.2.5 Data Processing Subsystem

As mentioned before, the sensor provides data to the receiving device in data processing subsystem. Then, we analyze the data, preparing for the 3D plot.

2.2.6 Link Subsystem

It mainly serves to the control system of the motors. We firstly use the code controller and then use the link part to control the moving path of the motor, which also has been discussed before.

2.3 Subsystem Requirements

2.3.1 Penetrate Subsystem

The main body of penetrate probe is a metallic rod and it encloses the piezo-electric force sensor (Kistler Instrumente, sensor type 9207) at its bottom. A thin conical mental tip is attached to the force sensor at the end of the rod for measuring penetration force. What's more, to make the detector lighter (one of the high-level requirements), we will choose the material and design the structure with light but strong material small size.

2.3.2 Control Subsystem

We are going to use the power of 5V for the motor and Li-ion Battery (3.0-4.2V) for the electric speed controller connects with the link subsystem through 2.4GHZ RF. As we mentioned before, force measurements are triggered by the encoder of the motor. And the electronic speed controller Thereby, users can define the speed, moving path and penetration depth, which meets the high-level requirements of range of moving Also, natural variations in the penetration speed (e.g. at the transition to a very hard layer) can be compensated and reaches an accurate measuring process (another high-level requirement). As for the vertical motor, it provides the speed of the probe about at 20mm/s.

2.3.3 Data Processing Subsystem

The receiving device uses I/O to receive data from pressure sensor. Data is written in files (*.pnt) which are stored on a common SD card. After analyzing, data will be sent to Interface Subsystem with 2.4 GHZ RF (Bluetooth).

2.3.4 User Interface Subsystem

Use 2.4 GHZ RF (Bluetooth) to interface with Data Processing Subsystem. Use code to transform data to charts and graphs to show the results intuitively.

2.3.5 Link Subsystem

It can use code to deliver user's command. Use 2.4 GHZ RF (Bluetooth) to interface with Electronic Speed Controller.

2.4 Tolerance Analysis

In the tolerance analysis, let's focus on the potential damage to the force sensors from ground conditions and the effect of temperature variations on the drift of the force sensor signals, which is a key risk to the successful completion of the project.

2.4.1 Effects of Ground Conditions

Scree or Rock Fields:
Risk: The main concern is the potential damage to the sensor from high bending forces when touching rocks.
Mitigation: Use a calibrated avalanche probe to measure the actual depth before penetration. This pre-measurement can prevent the penetrometer from impacting hard surfaces unexpectedly. Additionally, configuring the force overload range to a low value (e.g., 25 N) can prevent damage by stopping the penetration before excessive force is applied. Ensuring that the our micropenetrometer is securely pressed down to prevent upward movement is also crucial for avoiding damage.

Soil and Frozen Soil:
Risk: Embedment of fine materials on the penetrometer's tip, particularly into the force sensor, can occur, potentially affecting measurement accuracy.
Mitigation: Cleaning the tip after measurements in such conditions is recommended to ensure accurate subsequent readings. Reducing the maximal force to 25 N in uncertain soil types can also prevent damage.

2.4.2 Influence of Temperature

Temperature changes during measurements can cause drift in the force signal, affecting the accuracy of the micropenetrometer's readings. This drift is more pronounced under significant temperature gradients, such as when moving the device from a warm to a cold area or vice versa.

Observations:
Temperature Equilibrium: In conditions close to temperature equilibrium, the signal drift is slightly negative but minimal (¡0.2 mN/s), suggesting that temperature effects are manageable when the device and environment temperatures are similar.
Temperature Disequilibrium: Significant temperature changes induce a drift in the force signal, which can compromise measurement accuracy. This effect is particularly noted during springtime with high solar radiation.

Mitigation Strategies:
Operational Adjustments: To minimize the impact of temperature drift on measurements, it's recommended to shield the our micropenetrometer from direct sunlight and, if possible, operate it in shaded or cooler conditions to maintain a more stable temperature environment.

Design Considerations: Incorporating design features that minimize temperature effects on the sensor and electronics, such as thermal insulation or active temperature control mechanisms, can further reduce signal drift.

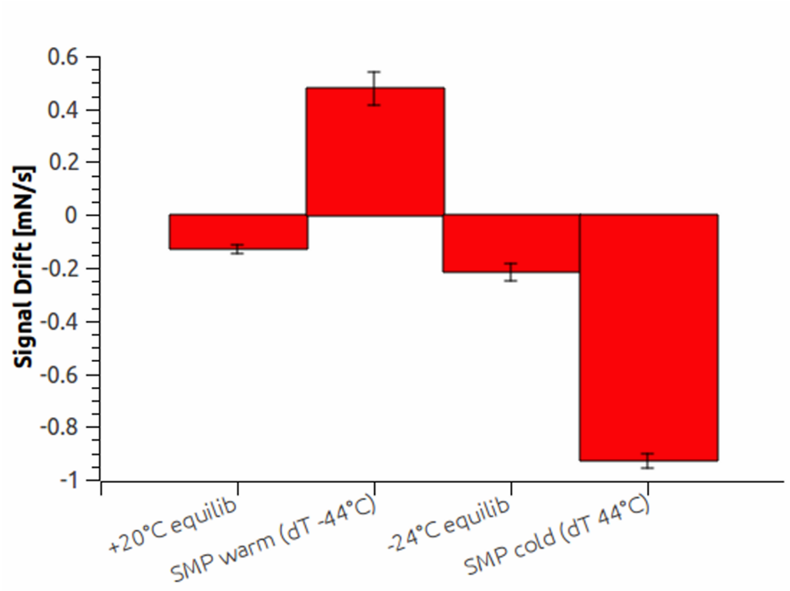

Figure 3: Observation

3 Ethics and Safety

In developing a portable micro-penetrometer for analyzing soil and snow structures, ethical and safety considerations are paramount, in alignment with the codes of conduct outlined by professional organizations such as IEEE and ACM. Ethical concerns center on the responsible collection and use of environmental data, respecting privacy where applicable, and ensuring that data is not manipulated or misused in a manner that could cause harm or misinform stakeholders, per IEEE Code of Ethics and ACM Code of Ethics and Professional Conduct. Safety issues include the physical operation of the penetrometer, which must adhere to industry standards for electronic devices and field equipment to prevent accidents during use. This involves compliance with state and federal regulations regarding the safety of electronic instruments and battery usage (e.g., IATA regulations for Li-Polymer batteries), along with campus policies on field equipment. Misuse of the penetrometer, such as operating it in unauthorized or sensitive ecological areas, could damage the environment or disrupt habitats; hence, operational protocols will be established and training provided to users. To avoid ethical breaches, all project development will be documented, and data integrity checks will be implemented. Potential safety concerns, such as the risk of injury from the device's moving parts or exposure to extreme environmental conditions, will be mitigated through design features like safety guards, automated shut-off mechanisms, and robust casing for electronic components. Regular safety audits and reviews of regulatory changes will ensure ongoing compliance and safe operation.