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Development and Evaluation of a Smart Soil Assessment System with Rapid Mechanical-Based Penetration Measurement and IoT System for Soil Strength in Precision Agriculture

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Abstract

In order to address the shortcomings of conventional evaluation techniques that depend on labor-intensive laboratory analyses and manual sampling, this study presents a real-time soil collection and penetration system intended to measure critical soil mechanical properties, such as compaction, penetration resistance, and strength, directly in the field. A microprocessor controls the system's unique sampling technique, which uses a penetration probe with force and displacement sensors to capture data instantly. Strong correlations between the results of conventional cone penetrometers and field testing done across a range of soil types allowed for faster operations and immediate data visualization. With future improvements targeted at enhancing adaptation to varied soil conditions and expanding automation capabilities, this cutting-edge technology improves soil profiling, which benefits precision agriculture, quicker building site evaluations, and efficient environmental monitoring.

Keywords: Real-Time Soil Assessment, Penetration Resistance, Soil Strength, On-The-Go Sensing, Soil Collection

Introduction

Soil mechanical properties such as compaction, shear strength, and penetration resistance are critical to agricultural productivity and geotechnical stability. High soil compaction, for instance—usually characterized by increased resistance to penetration—hinders root penetration, water infiltration, and nutrient uptake, hence preventing plant growth. In agriculture, crop performance and soil health are governed by these traits [1]. Unchecked, these factors have the potential to drastically lower agricultural productivity and soil sustainability. In geotechnical engineering, it is equally crucial to comprehend the mechanical behavior of soil. Cone penetration tests (CPTs) and other in-situ experiments are commonly used to determine the strength and strata of soil for safe foundation design and construction. Stratigraphic subtleties would be missed by sparse sampling, whereas the CPT provides near-continuous profiles of soil resistance with depth [2]. These examples demonstrate how accurate and timely knowledge of soil mechanical properties is essential for responsible decision-making in a variety of fields, whether the objective is to ensure structural stability or optimize crop management.

However, there are a number of drawbacks to traditional methods of assessing soil characteristics. Manual sampling and laboratory analysis have historically been the mainstays of soil evaluations. Soil cores are manually gathered, transported to labs, and examined for characteristics such as strength or nutrients. This method only produces low-resolution data and takes a lot of time and effort. In addition to requiring weeks for laboratory results, a single soil test may entail many manual processes (collection, handling, and lab preparation), which would delay any management action. Furthermore, traditional approaches generate isolated observations that might miss the substantial spatial diversity of soil conditions because samples represent distinct spots in a field [3]. Consequently, farmers and engineers are frequently left with imprecise information that hinders their capacity to promptly maximize resource utilization or design choices.

Traditional soil sample techniques, for instance, are "labor-intensive, time-consuming, and limited in spatial resolution," making them unsuitable for contemporary large-scale precision agriculture, according to Nguyen et al. Likewise, manual in situ penetration measurements (e.g., with a manual cone penetrometer) can be laborious and inconsistent. These handheld devices usually don't offer real-time data streams or instant feedback, and human operators struggle to maintain a consistent penetration rate, which causes variation in recorded resistance [4]. Data gathering is further hampered by the physical strain and slowness of hand probing in hard or dry soils. There is an obvious need for more effective soil monitoring solutions because of the drawbacks of traditional methods, which include high labor and time requirements, limited data density, and a lack of immediate findings.

Literature Review

2.1. Precision Agriculture

Recent technical developments and precision agriculture provide a way around these obstacles. In order to collect soil data in real time, there has been a notable trend over the last ten years toward the use of mobile sensors, automation, and Internet of Things connectivity. High-resolution, current soil data is necessary for decision support in precision agriculture frameworks that prioritize data-driven, site-specific management [5]. In response to this need, scientists and industry professionals have created a range of proximal soil sensors, such as mechanical penetrometers, optical spectrometers, and electrical conductivity mappers, which can be installed on tractors or robotic platforms and used to continuously measure soil characteristics as the vehicle traverses the field.

These developments make it possible to map soil variability quickly and with little assistance from humans. Mansoor et al., for instance, point out that farmers can now remotely monitor soil conditions in real time thanks to networks of smart sensors and Internet of Things devices, which enables prompt interventions like variable-rate tillage or irrigation [6]. Researchers have started combining sensors with field tools in the particular context of soil compaction and mechanics in order to assess penetration resistance and associated parameters "on the go." Some writers contend that in order to properly control within-field variability, real-time, continuous compaction mapping is required.

In order to improve the speed and consistency of data gathering, automated penetrometers and soil strength sensors have emerged in recent years. In contrast to manual probing, hydraulically operated, tractor-mounted cone penetrometers have been created to guarantee a consistent insertion rate and to electronically log data, producing compaction profiles that are quicker and more accurate. These devices demonstrate the possibility of combining automation and mechanical sensing: they significantly increase the density of measurements throughout a field by reducing operator error through on-the-go data logging and managing the probe's speed and angle. Additionally, the addition of wireless transmission to these instruments has begun to give engineers and farmers instant access to soil data. In order to provide real-time access to soil penetration resistance measurements in the field, Mahore et al. developed a portable penetrometer with a motorized, constant-rate drive and an Internet of Things-based data transmission system [7]. This type of device shows how combining an IoT connection with a mechanical sensor may significantly increase the usability and data flow of soil measurements.

A significant research gap still exists in the present soil monitoring instruments, despite these developments: many of the systems are either not completely automated or do not connect to the Internet of Things (IoT) for easy data exchange and feedback. Instead of taking use of continuous, connected data streams, the majority of farmers and practitioners still use semi-manual tools or standalone digital devices that need post-processing on their own. Even the more recent tractor-mounted penetrometers have drawbacks; some prototypes are heavy or only work with particular kinds of equipment, while others have design limits that limit how often or how deeply they may be measured. This implies that in reality, there is frequently no small, easy-to-use tool that allows one operator to gather and view soil mechanical data in real time as they traverse the field [8].

Additionally, data from several devices is not instantly accessible for analysis or decision-making across bigger farm management systems due to a lack of connection with IoT platforms. As a normal hand-pushed penetrometer “requires more time and effort,” Nisha et al. noted that they could send real-time compaction data to a mobile app by retrofitting it with an embedded microcontroller, GPS, and Wi-Fi module [9]. The drawbacks of manual and offline traditional technologies are highlighted in this case, as are the observable advantages of automation and connection, such as less human error and instantaneous data access. On-board sensing, IoT communication, real-time feedback, and penetration automation are all components of full systems that are still absent or not yet extensively used. Farmers and field engineers need a portable, integrated soil monitoring device on the ground, but large-scale, research-grade devices are essentially at a technological and practical distance [10].

In light of these shortcomings, the current study suggests creating a method for collecting and penetrating soil in real time in order to measure its mechanical characteristics. This development's justification stems from the necessity for a device that can autonomously sample or penetrate soil and provide real-time reports on important mechanical indications (such firmness or penetration resistance) without the time and effort required by traditional methods. High-resolution soil data collection with real-time user input would be made possible by combining mechanical sensing technologies (such as displacement sensors for depth and load cells for force) with Internet of Things connectivity [11].

For on-the-go measurements, the proposed device can be hand-carried or placed on small field vehicles due to its compact and portable design. Soil resistance profiles would be continuously recorded by this small, Internet of Things-enabled penetrometer, which would then send the data in real time to a cloud platform or a user's device for immediate visualization and analysis. There are several advantages to this method: it reduces human variability and saves labor by automating the time-consuming parts of soil testing; it significantly improves the spatial and temporal resolution of data by allowing measurements to be made continuously across a field; and it instantly connects the data to decision-making frameworks through the Internet of Things [12]. According to the ideas of smart farming and precision agriculture, the suggested system offers a feedback loop that enables soil conditions to be evaluated and addressed in the same field activity. For instance, an operator could find areas that need mitigation (like subsoiling) without waiting for lab results by using real-time maps of soil compaction. Similarly, an integrated real-time penetrometer could provide quick on-site soil strength profiling in geotechnical surveying, leading to quicker project choices.

2.2 Mechanical based sensor

Mechanical sensors can be used to measure the spatially varying degree of compaction, which is connected with the mechanical impedance (resistance) of the soil. Tolerance to soil loss is determined by soil strength sensors by design. Consequently, when a sensor is pushed or pulled through the soil, it detects parasitic (frictional and adhesive) forces that develop at the sensor-soil interface seen in Figure 1 [13] as well as resistance forces brought on by cutting, fracturing, and displacing soil.

Figure 1. Shank that connected with load cell, optical sensor and gamma ray spectrometer

The forces operating on tillage tools can be measured using strain gauges and load cells. The mechanical sensors are perfect for field application since they are inexpensive, incredibly sturdy, able to survive challenging field conditions, and easy to attach to a data collection system. The draught, vertical load, side force, and moments of tillage implements are frequently measured using load cells [14]. In a dynamic penetration test, the penetrometer is driven into the earth using a hammer or dropping weight. For a better correlation with soil physical properties like tilth or crop yields, relative density, unconfined compressive strength or shear strength, bearing value, or safe soil pressure, or for a better correlation with rolling resistance or wheel traffic capacity, a wide variety of penetrometers have been developed to provide quantitative measurements of soil penetration resistance [15].

2.3 Vertical Penetrometer

A vertical rod's force needed to pierce soil in order to collect data is known as soil penetration resistance [16]. It is usual practice to use a compression load cell to measure force. Resistance may be measured at different depths thanks to the ultrasonic sensor in certain penetrometers, which tracks the distance travelled as the cone penetrates. Because penetrometers can rapidly locate areas of high soil strength, they are helpful instruments [17]. As seen in Figure 2, manual type cone penetrometers are easy-to-use, affordable, and straightforward tools for figuring out the mechanical characteristics or penetrating resistance of soil (PR). They've been utilized extensively to examine optimum management strategies and tillage processes.

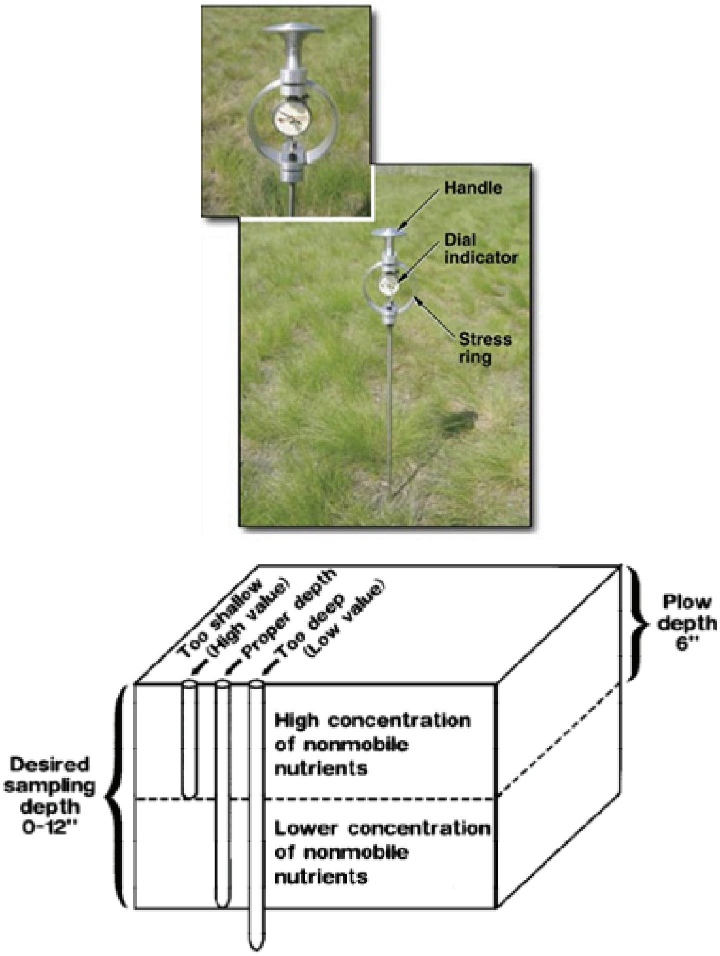


Figure 2. Example of vertical penetrometer that penetrates the soil

At a single point in time and place, the soil's penetrability is determined by the PR measured using a cone penetrometer. The resulting results frequently exhibit substantial geographical and temporal variability because of caverns or stones, aggregate density variations, and changes in bulk density and water content over time [18]. For each depth, four measurements at the corners of a 20-cm square were averaged at various periods of the year to capture temporal and spatial variability [19]. As a result of testing soil resistance brought on by an increase in soil density, a penetrometer may detect soil compaction in a saturated field. Penetrometer measurements, however, are only available at certain locations. This limits the capacity to continuously gather soil compaction data. The roots of most crops slow down when the soil strength is around 1500 kPa, and many plants stop growing when the soil strength is around 2500 kPa. With the ability to push a cone-shaped object steadily into the ground, cone penetrometers are one example of a device that can assess the strength or resistance of soil penetration at different depths [20].

Manual penetrometers are inefficient and vertical penetrometers are prone to inaccuracies when used in heavy and dry soils [21]. The crop, cultural methods, tillage depth, and soil type all affect the sampling depth since tillage and nutrient mobility in the soil can significantly affect nutrient levels in various soil zones [22].

Material and Methods

3.1 Real time and on the go for soil strength measurement

Development of a mobile, real-time system for measuring the mechanical characteristics of soil. Once the design of the portable measurement devices is finished in Solidworks, all parts will be constructed and manufactured using a rapid prototyping machine or 3D printer. Prior to being used in the field, the on-the-go measuring device prototype will be integrated to enable real-time measurement in the laboratory. We'll test how well the prototype works. To combine the data gathered by the selected sensor, a data collection system will also be created and incorporated [23]. We will design and programmed the PCB for the system. Figure 4 shows the schematic connection for the real-time soil sample collecting and penetration system for evaluating mechanical properties, incorporating IoT systems, while Figure 3 displays the block diagram.

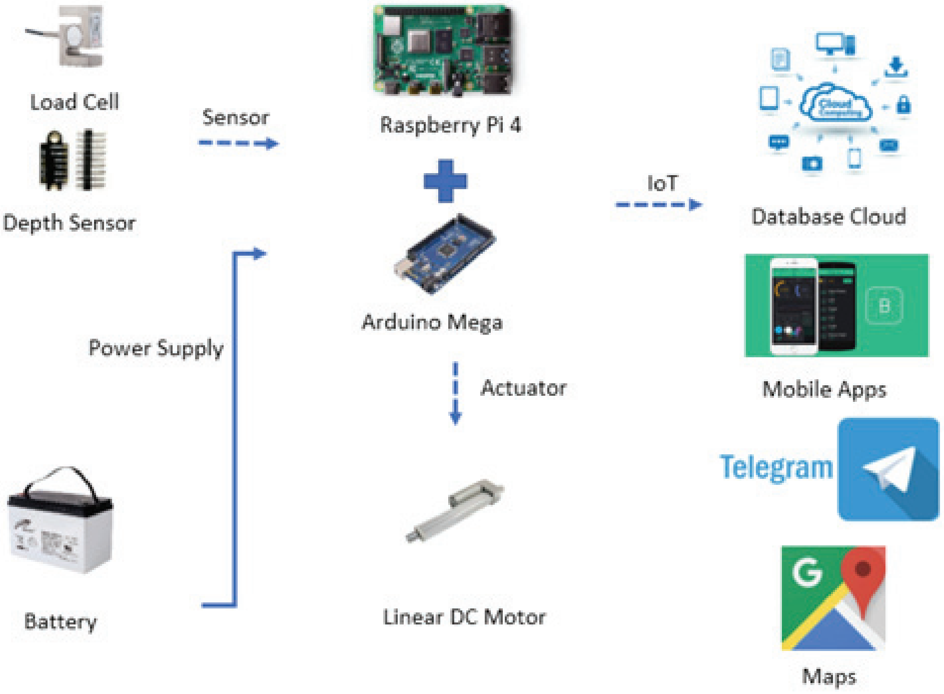


Figure 3. Block diagram for mechanical based penetration measurement system

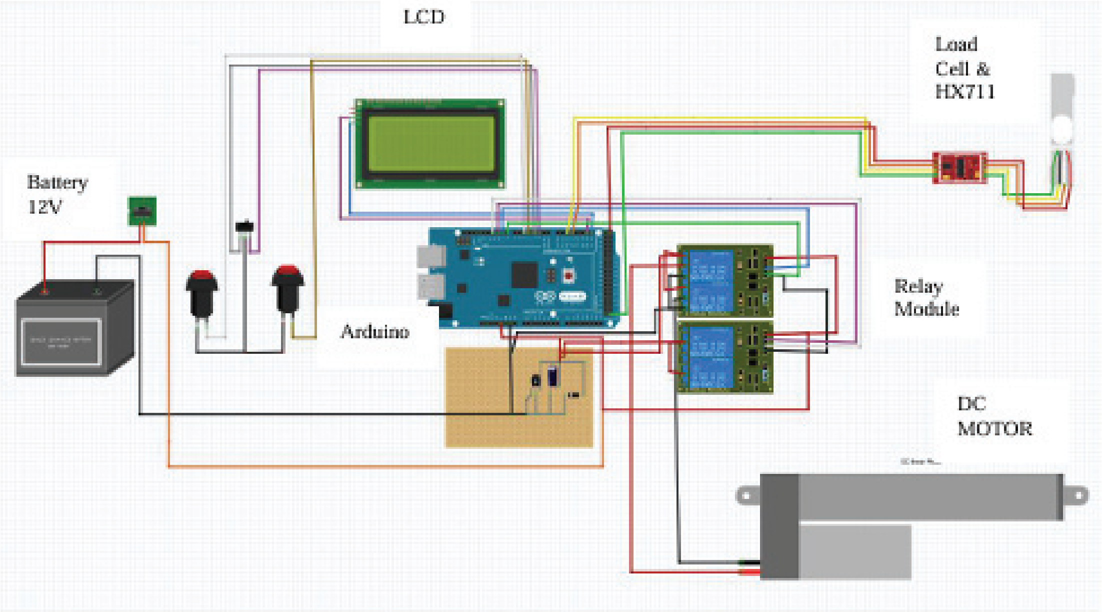


Figure 4. Schematic diagram for controller and IoT system

3.2 Soil Type

To ascertain the variations in soil compactions and strength, the strength of various soil field types is analyzed. Pineapple fields, palm oil plantations, and paddy fields are among the soil types that need to be measured. The forces applied to the soil will vary depending on the type of soil field being measured. The six types of soil are placed inside a container, as shown in Figure 5. Three of the six soil types—rock, sand, and laterite soil—will be the focus of the experiment.

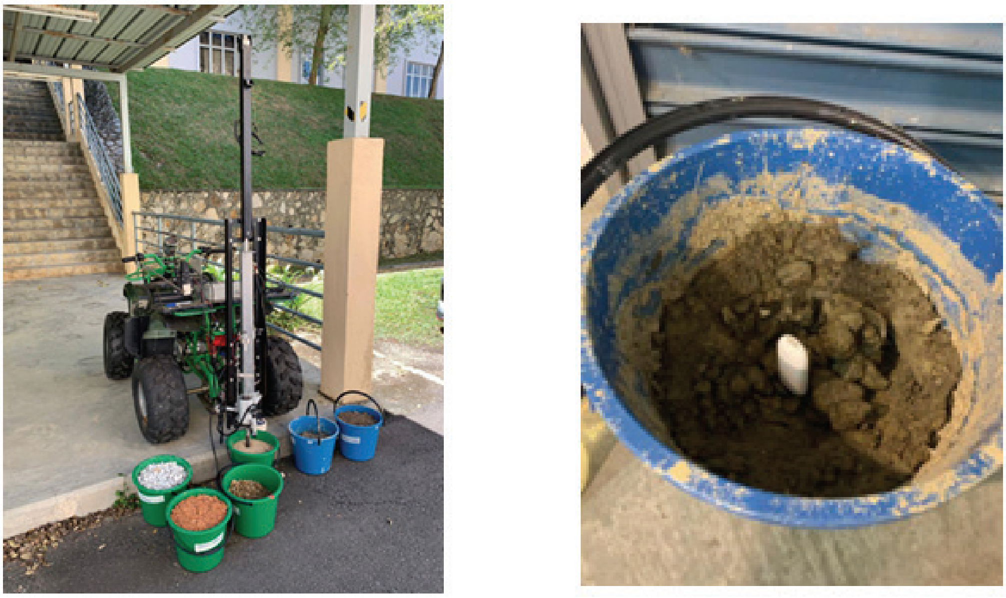
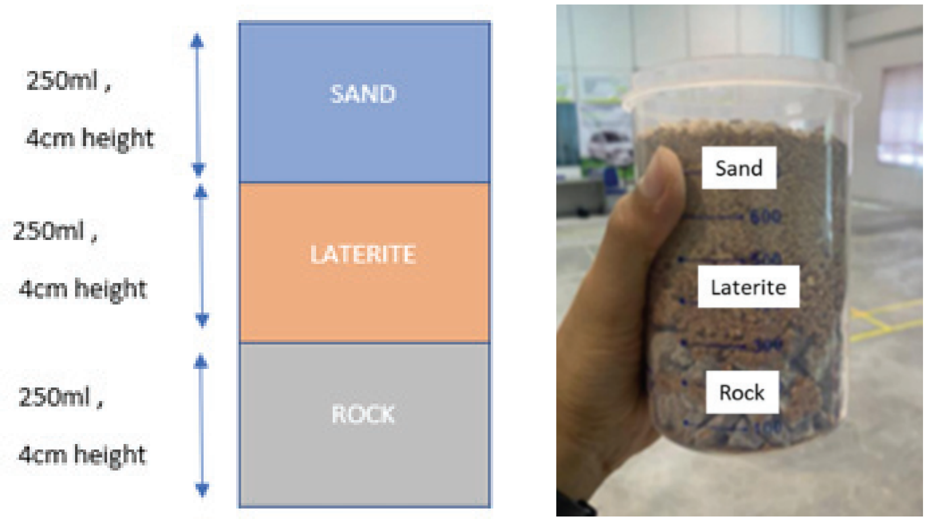


Figure 5: Experimental setup for soil penetration measurement

3.3 Combination of Texture of Soil

A classification tool called soil texture is used in both the field and the lab to identify different soil classes according to their physical characteristics. Combining three different soil types in one container is known as combination soil texture. As seen in the soil layer graphic, each soil is measured for 250 ml, and the total amount of soil in a container that holds 750 ml includes three distinct types of soil. Each soil layer has a depth of roughly 4 cm. When the penetration datalogger penetrates the soil texture, the force reading for the load cell will vary depending on the combinations of soil textures. The mixture of soil in a container is seen in Figure 6.



(a) Illustration of soil layer (b) Combination soil texture 3

Figure 6: Soil layer for experimental setup

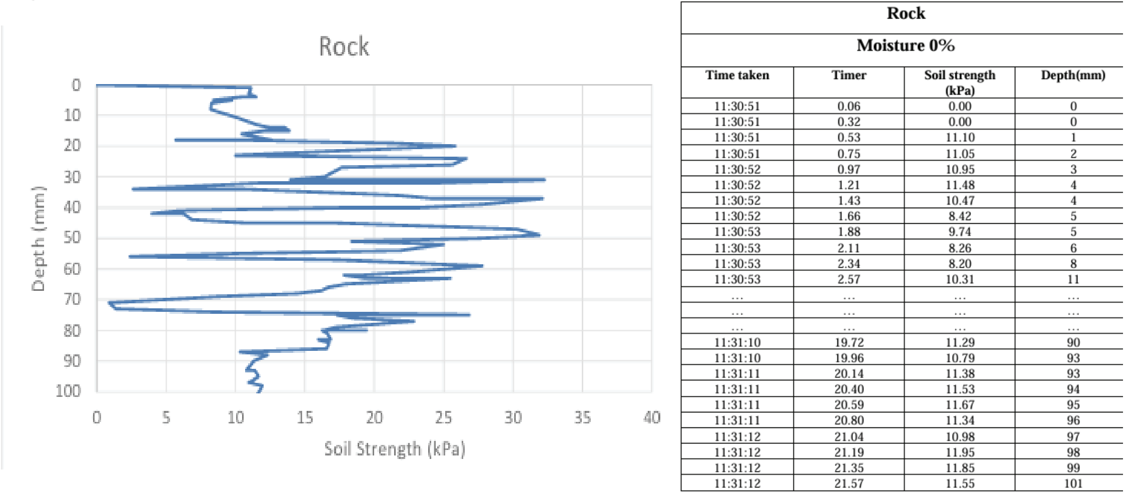
The depth versus force graph that indicates which field has the most soil compaction can be obtained using the on-the-go measurement. The compaction force has the potential to compress soil aggregates, which would be damaging to their structure. Compacted soil will inhibit the growth and penetration of roots into the subsoil.

Results and Discussions

The number of soil samples collected for every type of soil. The three different kinds of soil samples were selected in order to evaluate the mechanical properties and soil strength. The obtained data was saved as a PLX DAQ file after being combined with a load cell, depth sensor, and real-time data. Below are the mechanical parameters for three different types of soil, with measurements ranging from 0 to 11 mm and the final 10 mm.

4.1 Rock soil

Figure 7(a) shows that the force recorded during the penetration datalogger's penetration of the rock is unstable, whereas Figure 7(b) shows the depth (mm) against soil strength (kPa) as the penetration datalogger continues to enter the soil. Because of the rock's toughness, the penetration datalogger finds it difficult to penetrate it, which causes the readings to fluctuate. Because the DC linear actuator has trouble stretching and could damage the penetration datalogger if it penetrates the rock further, the depth of the datalogger is limited to 100 mm. The real-time rock sampling is shown in Figure 7(b).



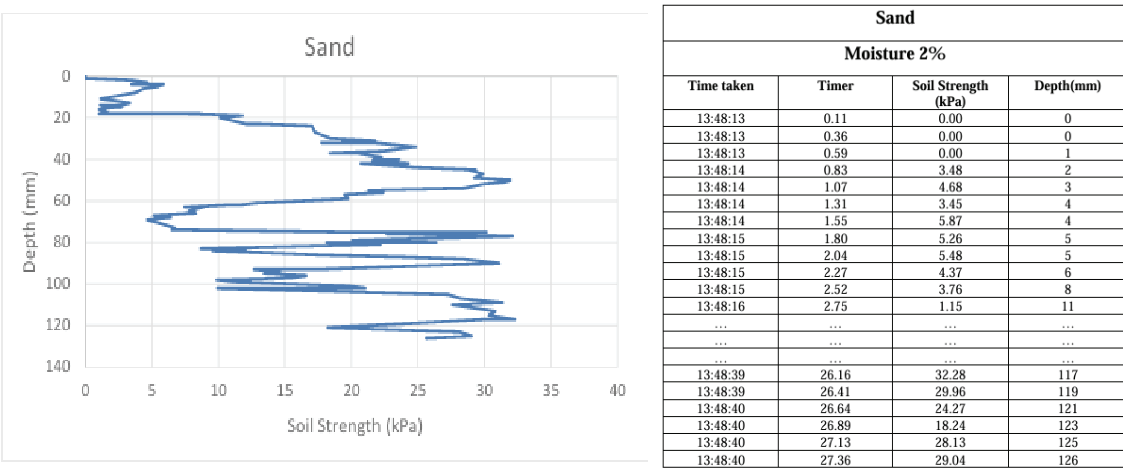
Rock			
Moisture 0%			
Time taken	Timer	Soil strength (kPa)	Depth(mm)
11:30:51	0.06	0.00	0
11:30:51	0.32	0.00	0
11:30:51	0.53	11.10	1
11:30:51	0.75	11.05	2
11:30:52	0.97	10.95	3
11:30:52	1.21	11.48	4
11:30:52	1.43	10.47	4
11:30:52	1.66	8.42	5
11:30:53	1.88	9.74	5
11:30:53	2.11	8.26	6
11:30:53	2.34	8.20	8
11:30:53	2.57	10.31	11
…	…	…	…
…	…	…	…
…	…	…	…
11:31:10	19.72	11.29	90
11:31:10	19.96	10.79	93
11:31:11	20.14	11.38	93
11:31:11	20.40	11.53	94
11:31:11	20.59	11.67	95
11:31:11	20.80	11.34	96
11:31:12	21.04	10.98	97
11:31:12	21.19	11.95	98
11:31:12	21.35	11.85	99
11:31:12	21.57	11.55	101

Depth against soil strength (kPa) results Soil strength measurement

Figure 7. Experimental result for depth (mm) against soil strength (kPa) rock soil sampling

4.2 Sand soil

Figure 8 displays the depth (mm) vs soil strength (kPa) of the sand at deeper penetrations of the penetration datalogger. Because the force of soil strength increases and decreases each time the penetration datalogger penetrates the sand, the force reading on Figure 8(a) indicates that the sand's soil qualities are unstable. The sand's soil strength and the force required to break through it are both high at 2% moisture content. The sand soil real-time sample is shown in Figure 8(b).



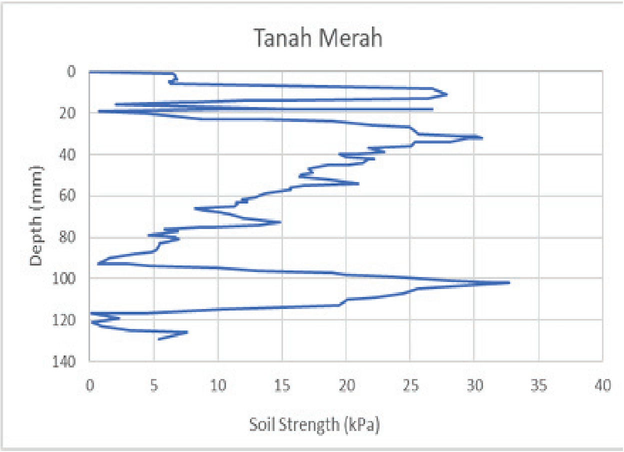
Sand			
Moisture 2%			
Time taken	Timer	Soil Strength (kPa)	Depth(mm)
13:48:13	0.11	0.00	0
13:48:13	0.36	0.00	0
13:48:13	0.59	0.00	1
13:48:14	0.83	3.48	2
13:48:14	1.07	4.68	3
13:48:14	1.31	3.45	4
13:48:14	1.55	5.87	4
13:48:15	1.80	5.26	5
13:48:15	2.04	5.48	5
13:48:15	2.27	4.37	6
13:48:15	2.52	3.76	8
13:48:16	2.75	1.15	11
…	…	…	…
…	…	…	…
…	…	…	…
13:48:39	26.16	32.28	117
13:48:39	26.41	29.96	119
13:48:40	26.64	24.27	121
13:48:40	26.89	18.24	123
13:48:40	27.13	28.13	125
13:48:40	27.36	29.04	126

Depth against soil strength (kPa) results Soil strength measurement

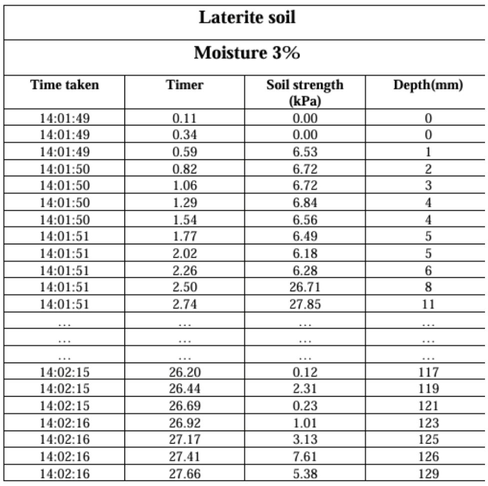
Figure 8. Experimental result for depth (mm) against soil strength (kPa) sand soil sampling

4.3 Laterite soil

When the penetration datalogger goes deeper into the soil, Figure 9's depth (mm) vs soil strength (kPa) shows that the soil is laterite. Because the laterite soil in the bucket is hollow, the force begins to decrease when the soil depth reaches 40 mm, according to the force reading on Figure 9(a). When it reaches a depth of 100 mm, the force increases considerably and then sharply decreases. This means that the mechanical properties of the soil are bad for plants since they can cause soil erosion. When the force reading is inconsistent over an extended period of time, the soil may cause erosion. The laterite soil real-time sample is shown in Figure 9(b).



Depth against soil strength (kPa) results



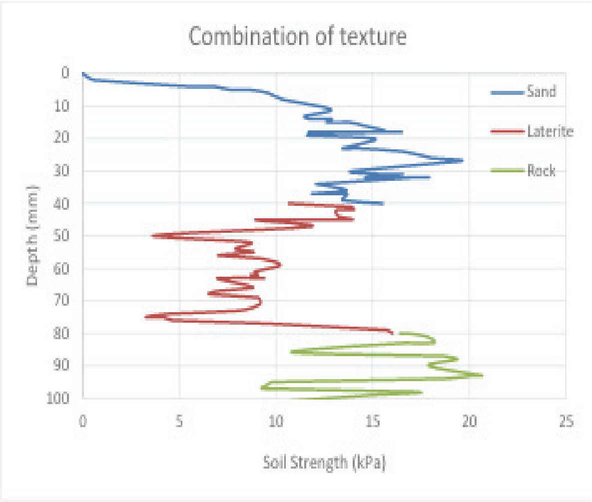
Laterite soil			
Moisture 3%			
Time taken	**Timer**	**Soil strength (kPa)**	**Depth(mm)**
14:01:49	0.11	0.00	0
14:01:49	0.34	0.00	0
14:01:49	0.59	6.53	1
14:01:50	0.82	6.72	2
14:01:50	1.06	6.72	3
14:01:50	1.29	6.84	4
14:01:50	1.54	6.56	4
14:01:51	1.77	6.49	5
14:01:51	2.02	6.18	5
14:01:51	2.26	6.28	6
14:01:51	2.50	26.71	8
14:01:51	2.74	27.85	11
...	...	...	...
...	...	...	...
...	...	...	...
14:02:15	26.20	0.12	117
14:02:15	26.44	2.31	119
14:02:15	26.69	0.23	121
14:02:16	26.92	1.01	123
14:02:16	27.17	3.13	125
14:02:16	27.41	7.61	126
14:02:16	27.66	5.38	129

Soil strength measurement

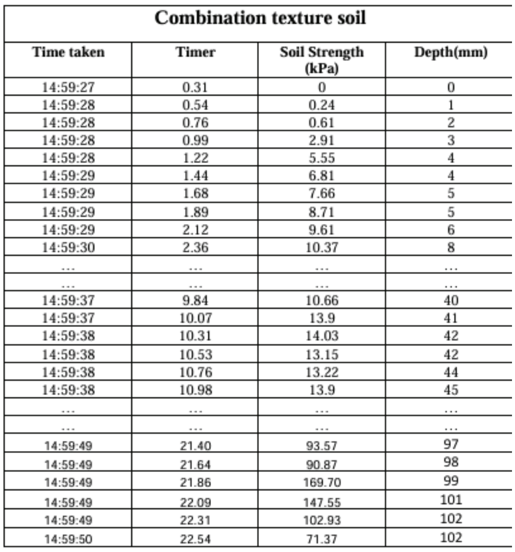
Figure 9: Experimental result for Depth (mm) against soil strength (kPa) laterite soil sampling

4.4 Soil Strength mechanical properties of combination soil triangle texture

The texture data shown in Figure 10 suggests a composite texture of sand, laterite, and rock, which is based on the soil layer tests described in Figure 6. The distance that the datalogger penetrates the soil during the first 0–11 mm and the last 10 mm is shown in Figure 10 below. The combination texture soil of three different types of soil—sand, laterite, and rock—is shown by the depth (mm) vs soil strength (kPa) in the table and graph above. According to the investigation, Figure 10's graph depicts three different soil compaction layers. The topmost layer, measuring 40 mm, indicates that the sand's strength is increasing. Because of the reduced soil compaction, the force reading is declining in the second layer of soil, which is laterite and ranges in thickness from 40 to 80 mm. The force applied to the rock is increasing because of its hard structure, as seen by the third layer, which is the bottom layer between 80 and 100 mm. Because the DC linear actuator has trouble stretching and could damage the penetration datalogger if it enters the rock deeper, the depth of the penetration datalogger at the third layer only reaches 100 mm. This goal is to investigate the force of three different types of soil simultaneously.



Depth against soil strength (kPa) results



Combination texture soil			
Time taken	**Timer**	**Soil Strength (kPa)**	**Depth(mm)**
14:59:27	0.31	0	0
14:59:28	0.54	0.24	1
14:59:28	0.76	0.61	2
14:59:28	0.99	2.91	3
14:59:28	1.22	5.55	4
14:59:29	1.44	6.81	4
14:59:29	1.68	7.66	5
14:59:29	1.89	8.71	5
14:59:29	2.12	9.61	6
14:59:30	2.36	10.37	8
…	…	…	…
…	…	…	…
14:59:37	9.84	10.66	40
14:59:37	10.07	13.9	41
14:59:38	10.31	14.03	42
14:59:38	10.53	13.15	42
14:59:38	10.76	13.22	44
14:59:38	10.98	13.9	45
…	…	…	…
…	…	…	…
14:59:49	21.40	93.57	97
14:59:49	21.64	90.87	98
14:59:49	21.86	169.70	99
14:59:49	22.09	147.55	101
14:59:49	22.31	102.93	102
14:59:50	22.54	71.37	102

Soil strength measurement

Figure 10: Experimental result for Depth (mm) against soil strength (kPa) combination texture soil

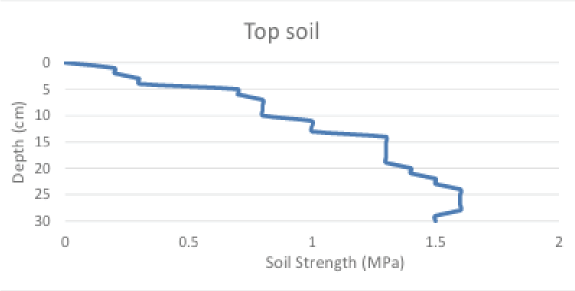
4.5 Comparison between top soil and deep soil

The manual penetration datalogger data of soil samples for palm oil that were gathered from UiTM, Jasin. The soil samples were compared at various points between the top soil (0 cm-30 cm) and the deep soil (30 cm-60 cm). The moisture percentage of the soil at each location in the soil sample was also included to the data. The comparison between top soil and deep soil for plots 1 and 2 is displayed in Figures 11 and 12. Force is the storage format for the measurement data (N). The data conversion to penetration resistance is displayed below.

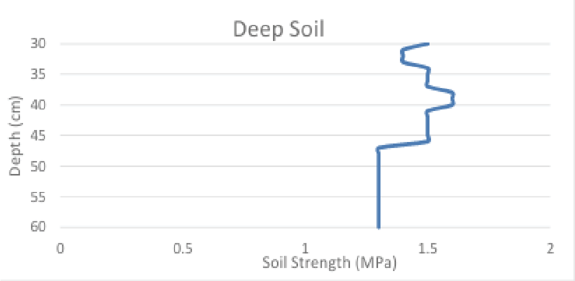
Cone Type = 2.0 cm^2, 60 °

$$Resistance\ to\ penetration\ in\ megapascal = \frac{Force\ (N)}{S\ (cone\ surface\ in\ mm^2)}$$

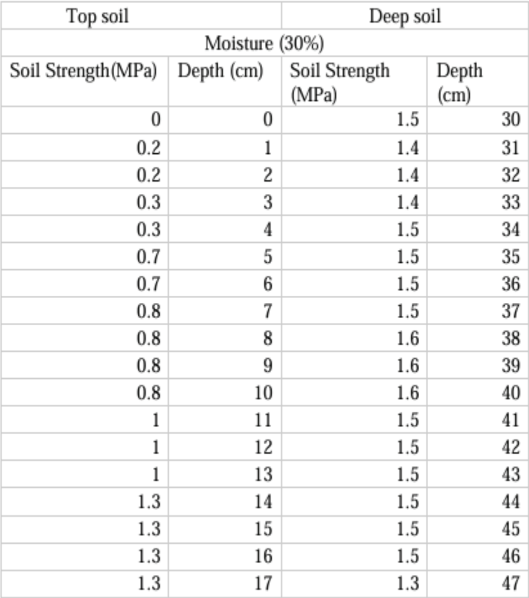
Plot 1



a) Soil strength top soil plot 1



b) Soil strength deep soil plot 1

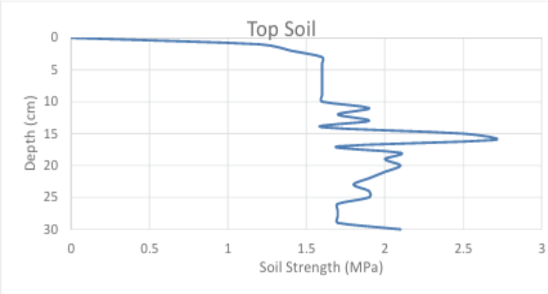


Top soil		Deep soil	
Moisture (30%)			
Soil Strength(MPa)	Depth (cm)	Soil Strength (MPa)	Depth (cm)
0	0	1.5	30
0.2	1	1.4	31
0.2	2	1.4	32
0.3	3	1.4	33
0.3	4	1.5	34
0.7	5	1.5	35
0.7	6	1.5	36
0.8	7	1.5	37
0.8	8	1.6	38
0.8	9	1.6	39
0.8	10	1.6	40
1	11	1.5	41
1	12	1.5	42
1	13	1.5	43
1.3	14	1.5	44
1.3	15	1.5	45
1.3	16	1.5	46
1.3	17	1.3	47

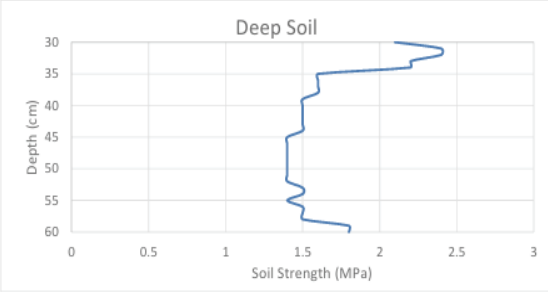
c) Top and deep soil strength

Figure 11: Comparison top soil and deep soil plot 1

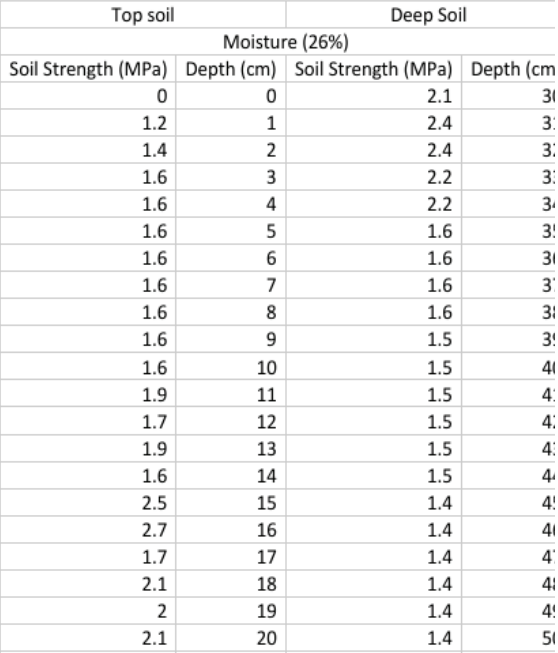
Plot 2



a) Soil strength top soil plot 2



b) Soil strength deep soil plot 2



Top soil		Deep Soil	
Moisture (26%)			
Soil Strength (MPa)	Depth (cm)	Soil Strength (MPa)	Depth (cm
0	0	2.1	3
1.2	1	2.4	3
1.4	2	2.4	3
1.6	3	2.2	3
1.6	4	2.2	3
1.6	5	1.6	3
1.6	6	1.6	3
1.6	7	1.6	3
1.6	8	1.6	3
1.6	9	1.5	3
1.6	10	1.5	4
1.9	11	1.5	4
1.7	12	1.5	4
1.9	13	1.5	4
1.6	14	1.5	4
2.5	15	1.4	4
2.7	16	1.4	4
1.7	17	1.4	4
2.1	18	1.4	4
2	19	1.4	4
2.1	20	1.4	5

c) Top and deep soil strength

Figure 12: Comparison top soil and deep soil plot 2

Plots 1 and 2 have moisture readings of 30% and 26%, respectively. Because the compaction properties at depths of 0 cm to 30 cm are different from those at depths of 30 cm to 60 cm, the force measurements for topsoil and deep soil are different. When the penetration datalogger enters the soil, the force is affected by the moisture of both plots. The maximum force of 1.6 MPa is shown in plot 1 at 30% moisture, while the maximum force of 2.7 MPa is shown in plot 2 at 26% moisture. The force at which the penetration datalogger enters the soil will change depending on the moisture percentage. As a result, less effort is needed to penetrate the soil when the moisture percentage is higher.

Conclusions and Future Tasks

The design, construction, and study of a real-time soil collecting and penetration device that works on any surface are discussed in the paper. The mobile platform and actuator were utilized to reduce the amount of time and energy required for analysis during the soil sample process. To determine its strength, a load cell is inserted into the ground and measures the force acting on it. The length of time the auger should be in the ground is indicated by a depth indicator. A graph that displays the force against the strength of the soil is created when a load cell and a depth sensor are combined. Ultimately, every objective was accomplished, including creating an all-terrain vehicle (ATV) that can monitor the vertical force on any surface by collecting and penetrating soil in real time. A vertical penetration datalogger, a depth monitor, and a load cell combine to provide real-time soil collection and penetration. The second objective, which was to develop a method for measuring the mechanical properties of the soil while on the go and in real time, including the penetration and vertical breaking forces, has also been accomplished. Examining the effectiveness of the developed real-time algorithm is the third objective. Measure the force required for the penetration datalogger to penetrate various soil types to determine the mechanical characteristics of soil while on the go. This will show the soil's mechanical characteristics at every distance the actuator travels.

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