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Multi Sensor Iot Driven System For Permeability Assessment On Sandy Clay Soil

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Abstract - The evaluation of permeability, a key element to geotechnical engineering, has traditionally been determined using labour-intensive laboratory methods. In this study, a new automated system for assessing soil permeability has been designed through an Arduino microcontroller. Real-time hydraulic head is maintained by the sensors that collect real-time water flow and pressure information together with automated control. Through the utilization of the Arduino platform, the system is able to acquire, process and control data autonomously hence enable continuous and autonomous testing. Calibration and validation of the system were performed relative to the conventional permeability test procedures, employing several soil materials. Precise coefficients were recorded, test times were significantly reduced, and human error potential was limited by the system. The developed system shows a cost-efficient and quick permeability assessment technique that can be applied in the lab or the field ensuring better quality of data and repeatability.
***Key Words*:** Permeability, Arduino, Automation, Soil Testing, Geotechnical Engineering

1.INTRODUCTION

Permeability, an essential property of porous substances, is an important determinant of the ease of fluid movement through this intricate network of interlinked voids and has a substantial contribution to make to multiple scientific and engineering disciplines...This hence calls for precise measurement of permeability in the effective analysis and control of these multidisciplinary systems. Permeability evaluations in geotechnical engineering often use laboratory tools – constant head and falling head permeameters (Elhakim, 2016). Though widely employed, old methods tend to demand attentive manual measurements, long data registration, thereby placing them at risk of errors and risky to implement (Alika et al., 2020). Moreover, the nature of the soil samples and potential inconsistency of tests performed can compromise the reliability and reproducibility of permeability measurement (Fajobi et al. 2014). What is necessary in order to overcome these barriers is the creation of automated and more accurate techniques for identifying permeability, which would allow limiting the human element and boost the accuracy and speed of testing.Newly implemented automated techniques, including the use of cost-effective and flexible microcontrollers such as Arduino,are a useful way forward in modernizing permeability testing procedures.

The use of Arduino-based systems for permeability testing is practically a sound approach for fixing the imperfections of manual testing practice .Because of its open-source design and straightforward user interface, Arduino facilitates automation of a wide range of testing protocols as it can create accurate control of the flow rates and allow flexible real-time collection of data (Bruno et al., 2021). It is possible to carry out fully automated permeability tests when sensors, actuators, highly programmable algorithms and Arduino are used to minimize the manual steps and increase accuracy of testing procedures. In addition, real-time data logging on Arduino makes it possible to constantly monitor parameters that matter, such as pressure, flow rate, and temperature, for a more thorough and accurate evaluation of the material's permeability.

2. Literature Review

The use of machine learning algorithms on traditional logs and the match them to core data allows for more exact reservoir simulation and well placement (Cheddad, 2023). The main goal of this research was to assess predictive abilities of each of the three machine learning algorithms for permeability, as well as to determine the most effective approach (Cheddad, 2023). Nevertheless, while research improved experimental and theoretical methods for measuring permeability, the protocols of experimental research are often under described (Sommi, et al., 2023). Permeability has proven to be very significant in various disciplines such as digital rock physics, membrane systems, geological carbon storage programmes, and medical research; and this has been stressed by several studies (Kashefi & Mukerji, 2021). The machine learning algorithms have been utilized in some research to forecast changes to porosity and permeability (Erofeev et al., 2019). Machine learning has been used to quantify rock porosity and permeability in a few studies but these practices are both inaccurate as well as time consuming (Iklassov et al., 2022).

Numerical solvers of the past and more modern studies of flow in porous media and transport share a limitation:<< There is a general limitation in the ease with which they can vary parameters such as the initial and boundary conditions, relative permeability, absolute permeability, porosity maps, and source terms (Diab et al., 2023). That is, any variation of any parameter entails retraining of the neural network or application of transfer learning (Diab et al., 2023). Physics-informed neural networks are among those that have moved to the fore as a strong procedure for handling partial differential equations which include many physical processes (Diab et al., 2023). By combining the power of the neural network with the physical constraint, the PINNs are capable of dealing with such complicated scenarios both specifically and in accordance to

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underlying scientific laws. Such methods are used to define the performance of petroleum reservoirs. Deep learning improvements led scientists to search for machine-learning approaches that could effectively determine the physical properties, thus removing the need for manual experiment (Iklassov et al., 2022).

3 Experimental Set Up

Sandy clay soil is taken from a preproposed site near a quarry terrain.Permeability of soil or in other words flow of water through the soil. Soil permeability is a measure of how easily water can move through the soil .It is dependant on the size and continuity of the pores between soil particles. Permeability controls almost every thing from drainage and irrigation to the stability of structures constructed over soil . For instance, knowing about soil permeability is vital for preventing leaks from underground storage tanks . Well, fine and well-structured soils have larger pores, are highly permeable, and have a lots of pores that connect nicely together. If the soil is not fully saturated that presence of air can stop path of water and decrease permeability. Examples of environmental factors include climate, groundwater, drainage, vegetation etc; it affects the permeability .Permeability can be measured in lab by making soil column under controlled condition such as in initial condition under saturated and steady water pressure condition, it can also be estimated by using models. If the soil is expansive by the nature of being expanded in water, it can be stabilized by red mud, permeability of stabilized specimen is generally low and the selection between the constant head permeability test and the variability head permeability test mostly depends upon the type of the soil to be investigated .
Constant Head Test: This test is most suited to soils of relatively high permeability and so might include sands and gravels. In thru this test, in this test a steady water level head is kept during thru the test and the amount in the water flowing through the soil in a given interval is measured. Due to the soil's high permeability, a measurable volume of water will pass through the sample in a realistic amount of time, permitting precise identification of permeability.
Variable Head Test: This test is more suited for soils of low permeability such as silts and clays. In this test, the water level (head) decreases during the test, the rate of decreasing water level is measured. Because of low soakage of soil the water level on the graph falls steadily enough to permit precise measurement

3.1 Automated Variable Head

An automated variable head test streamlines the traditional variable head permeability test, making it more efficient and consistent .Instead of manual readings, sensors and automated systems are used to monitor the water level and record data.The soil sample is prepared and placed in the testing apparatus, similar to a standard variable head test.Sensors, such as water level sensors, with automatic water level detection via analog sensors and real-time data display using an I2C LCD are connected to a data acquisition system. The system automatically records the water level as it falls over time.The data is then used to calculate the coefficient of permeability.The main advantage is reducing manual labor, minimizing human error, and improving the repeatability of the test.

Table -1: Components Required

Component	Description
Arduino Uno	Main microcontroller
16x2 I2C LCD	For displaying real-time values
4 Bare-wire sensors	Placed every 10 cm from top to bottom (90, 80, 70, 60 cm)
Push switch (pushbutton)	Used to start/reset the test
Water reservoir + soil column	Setup for falling head method

3.1.1 Sensor *Placement*

- A3 at 90 cm
- A2 at 80 cm
- A1 at 70 cm
- A0 at 60 cm

Water drops through each level due to soil permeability.

Each drop below a sensor is recorded on a timer. Convective K is calculated in real time from the differencing of time and height differences between a pair of successive sensors.

EQUATION

$K = (a \times L / A \times t) \times \ln(h_1 / h_2)$

- K = coefficient of permeability (cm/s)
- a = cross-sectional area of standpipe (0.785 cm²)
- L = length of soil sample (10 cm)
- A = cross-sectional area of soil (78.54 cm²)
- t = time taken for water to fall from h_1 to h_2
- h_1, h_2 = head heights between sensors (e.g., 90 to 80 cm)

Each time water drops below a sensor, the time is logged. Using the difference in time and height between successive sensors, K is calculated in real-time.

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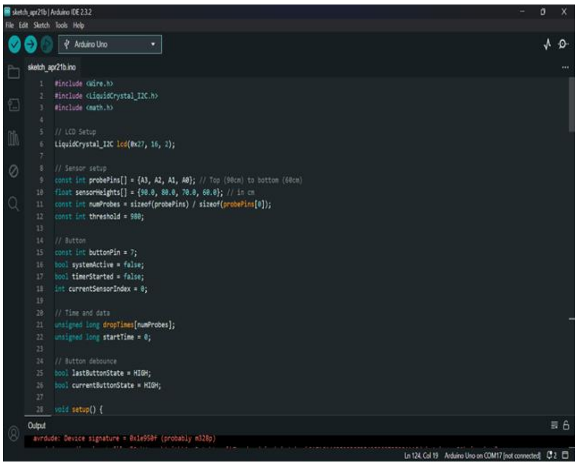

. **Fig -1**: A Bit From Sample Coding

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(a) (b)

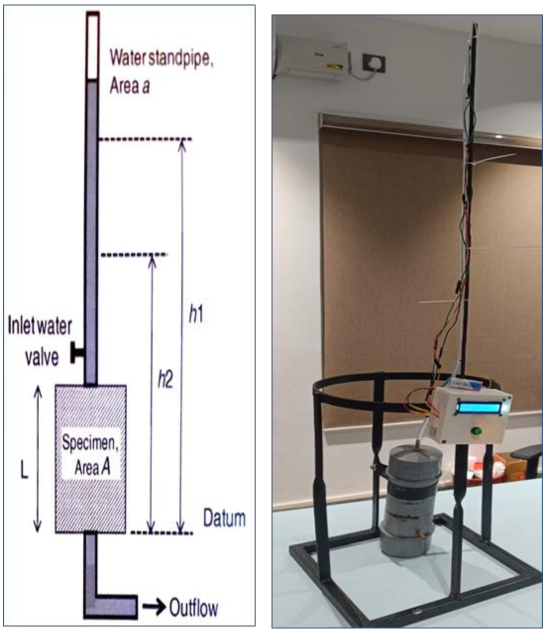

Fig -2,a): schematic of variable head2b)automated machine

Table -2: Result from Laboratory

h_1	h_2	Time(sec)	k	avg
90	80	.58	.003	.002549 cm/sec
77	67	1.08	.002038	
65	55	1.10	.00270	

Table -3: Result from automation

H_1	h_2	Time (sec)	k	avg
90	80	4.5	.00256	.00247 cm/s
77	67	7.5	.00243	
65	55	6.4	.00241	

Table -4: Both Results

method	Permeability k
automated	.00247cm/sec
laboratory	.002549 cm/sec

4 Results And Discussion

These values of hydraulic conductivity (k) as mentioned show how freely water can move through the soil (Contreras-Ferreyra et al., 2025). Lower values indicate more restricted movement of water through the soil, and the higher value means opposite.

From the presented data, I found that the automated method gave you a slightly larger value of permeability than the laboratory method. This could be due to differences in the stage of the soil sample collected, differences in the ways the tests were conducted, or the precision of instruments used (Wietsma et al., 2009). A permeameter can do constant flux, constant head, and falling head tests on k in an automated way (Wietsma et al., 2009). It should also be noted that, although these methods can be slightly more time-consuming compared to in-situ tests, they can offer precise values of hydraulic conductivity (Diminescu et al., 2019).

5 CONCLUSIONS

The study on automated variable head permeability test using Arduino IDE has successfully demonstrated the promise of miniaturisation of microcontroller based automation in laboratory procedures used in geotechnical field, particularly for testing the permeability properties of fine grained and silty soils.

The traditional variable head test, which has been widely practiced, has manual measurement errors, inconsistent readings, and time delays. On the other hand, the Arduino-controlled automated system developed in this study enabled very precise, ongoing, real-time monitoring of water levels falling in the standpipe, thus making it possible to determine the coefficient of permeability more accurately.

Salient features and findings of the study are:

System Performance & Functionality
Automated Water Level Monitoring: Application of ultrasonic or capacitive sensors connected to an Arduino microcontroller

enabled constant detection of the water head with little human intervention.

Real-Time Data Logging: The system was designed to take head readings at predetermined times and store them through an SD Card or send them to a connected device doing away with manual stopwatch errors.

User Programmability: The setup was easily adaptable because of flexible programming with the Arduino IDE for different soil specimen lengths, diameters, and initial head conditions.

Improved Accuracy: By minimizing the instance of human error in reading and timing, the automated setup assured more re-producible permeability results, particularly for soils of very low flow rates.

Advantages Over Manual Testing

Time Efficiency: By continuously measuring, long duration tests could operate unattended, increasing lab productivity.

The interface was student, technician and, researcher friendly, meaning that the operators and custodians needed little to no training of how to use and modify the system.The outputs of the automated system proved to be comparable with standard IS: 2720 outputs thereby confirming its reliability. The system performed particularly well for soils with moderate to low permeability – the lateritic soils that are most common in Ernakulam provided granular insight into flow behaviour.

In essence, this research proved that Arduino-based automation of the variable head permeability test is not only technologically but also practically implementable. It enhances the reliability, efficiency and scalability of geotechnical permeability testing and is particularly valuable in academic laboratories, research facilities, field quality control stations.

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REFERENCES

1. Alfarisi, O., Raza, A., Ouzzane, D., Li, H., Sassi, M., & Zhang, H. (2021). Morphology Decoder: A Machine Learning Guided 3D Vision Quantifying Heterogenous Rock Permeability for Planetary Surveillance and Robotic Functions. arXiv (Cornell University). https://doi.org/10.48550/arxiv.2111.13460
2. Alika, J. O., Adeogun, B. K., & Ajibike, M. A. (2020). Design, Fabrication, Evaluation and Calibration of an Improvised Soil Permeameter for Measurement of Soil Hydraulic Conductivity. Journal of Applied Science and Environmental Management, 24(5), 867. https://doi.org/10.4314/jasem.v24i5.22
3. Bruno, F., Marchis, M. D., Milici, B., Saccone, D., & Traina, F. (2021). A Pressure Monitoring System for Water Distribution Networks Based on Arduino Microcontroller. Water, 13(17), 2321. https://doi.org/10.3390/w13172321
4. Cheddad, F. A. (2023). Enhancing Petrophysical Studies with Machine Learning: A Field Case Study on Permeability Prediction in Heterogeneous Reservoirs. arXiv (Cornell University). https://doi.org/10.48550/arxiv.2305.07145
5. Diab, W., Chaabi, O., Alkobaisi, S., Awotunde, A. A., & Kobaisi, M. A. (2023). Learning generic solutions for multiphase transport in porous media via the flux functions operator. Advances in Water Resources, 183, 104609. https://doi.org/10.1016/j.advwatres.2023.104609
6. Elhakim, A. F. (2016). Estimation of soil permeability. Alexandria Engineering Journal, 55(3), 2631. https://doi.org/10.1016/j.aej.2016.07.034
7. Erofeev, A., Orlov, D., Ryzhov, A., & Koroteev, D. (2019). Prediction of Porosity and Permeability Alteration based on Machine Learning Algorithms. arXiv (Cornell University). https://doi.org/10.48550/arxiv.1902.06525
8. Fajobi, A. B., Falade, F., Adepelumi, A. A., & Akindulureni, O. (2014). Evaluation of hydraulic conductivity of lateritic soils using integrated approach: southwestern Nigeria case study. International Journal of Advanced Geosciences, 3(1), 1. https://doi.org/10.14419/ijag.v3i1.3552
9. Gärttner, S., Alpak, F. O., Meier, A., Ray, N., & Frank, F. (2023). Estimating permeability of 3D micro-CT images by physics-informed CNNs based on DNS. Computational Geosciences, 27(2), 245. https://doi.org/10.1007/s10596-022-10184-0
10. Iklassov, Z., Medvedev, D., & Nazarov, O. (2022). AI for Porosity and Permeability Prediction from Geologic Core X-Ray Micro-Tomography. arXiv (Cornell University). https://doi.org/10.48550/arxiv.2205.13189
11. Jamalian, M., Safari, H., Goodarzi, M., & Jamalian, M. (2018). Permeability Prediction Using Artificial Neural Network and Least Square Support Vector Machine Methods. Proceedings. https://doi.org/10.3997/2214-4609.201801506
12. Kashefi, A., & Mukerji, T. (2021). Point-cloud deep learning of porous media for permeability prediction. Physics of Fluids, 33(9). https://doi.org/10.1063/5.0063904

BIOGRAPHIES (Optional not mandatory)

1'st Author Photo	Description about the author1 (in 5-6 lines)