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Performance Evaluation of Bar Load Cell Sensing System for Soil Moisture Measurement

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Abstract. The open-source microcontroller Arduino is simple to program, erase, and reprogram at any moment. It is an open-source computing platform for creating and programming electronic devices based on basic microcontroller boards. In agriculture, soil moisture content must be monitored soil monitoring continuously to understand the relationship between soil moisture content status and plant water use to minimize under and over-irrigation. Current methods have a short lifespan due to possible corrosion on the electrode. In this project, we introduce a new indirect method for monitoring soil moisture, especially for soil in the container or pot, based on a low-cost bar-based load-cell sensor with an acrylic plate. This study's objectives were to compare the number of bar load cell sensors that affect the soil weight and to formulate a calibration model to predict soil moisture content using soil weight. A model design of 10 kg and 5 kg bar-based load cell sensors will be used to compare the number of bar load cell sensors affecting the soil weight. The measurement result of each method was very similar and constant for the various positions on the design. There is no significant difference in average soil weight for any technique, and there is no difference in average soil weight for each sample. R^2 values and the calibration equation were tabulated in Table 3.

Keywords: soil moisture; load cell sensor; soil moisture sensor; acrylic plate;

1. Introduction

Increasing the food demand in our country needs to take serious action to maintain food security. Agricultural development is crucial to improving food security and nutrition. In agriculture, the moisture content is significant to monitor to produce the maximum crops for a farmer. Producers must have a solid understanding of soil moisture management to manage irrigation effectively. Therefore, knowledge of water dynamics in the soil is essential for estimating its water condition and effectively managing irrigation [1].

TDR is the most efficient method to ascertain the soil's moisture content because it involves the speed of an electromagnetic signal through a substance that changes with the material's dielectric. Previous studies discuss the most reliable data provided by TDR [2]. The TDR technique features simple probes, making it possible to design individual probes [3]. A TDR probe might consist of two or three plain stain-steel wires placed into the ground. This makes the investigations affordable and ideal for large-scale water content measurements [3]. However, the low-cost resistance sensor may have a short lifespan due to possible corrosion on the electrode [4].

There needs to be more research done on using bar load-cell sensors to measure soil moisture content and uncontacted sensor for monitoring soil moisture content. This project introduces a new method for monitoring the soil moisture content without requiring it compared to current techniques. This method is cheap, easy, and accurate, but it is time-consuming, demanding, and challenging to apply to rocky soils [2]. The destructive gravimetric methodology approach is commonly used to determine soil moisture content [1].

Monitoring the soil moisture content using the current method obtains several issues. The existing method may be rusty. In this research, a load cell sensor is used to monitor the soil moisture content. This new technique for tracking soil moisture content is introduced without requiring direct contact. This innovative technology could be helpful for long-term massive network monitoring that does not require regular maintenance or calibration. The objectives of this study were (1) to compare does the number of bar load cell sensor affect the soil weight; and (2) to construct a calibration model for predicting soil moisture content using soil weight. The destructive gravimetric technique will be used to correlate the weight of the soil in the pot with the actual moisture content of the soil.

2. Sensor System Design

The Arduino is utilized to control the entire procedure in this project. The load cell transmits (Figure 1) an electrical analogue voltage to the HX711 Load Amplifier Module when it detects weight. The HX711 is a 24-bit ADC that amplifies and digitally converts the output of a load cell. This increased value is then sent to the Arduino. Arduino now calculates and converts the HX711 output to weight values. Like other microcontrollers, Arduino can perform minicomputer functions by receiving inputs and directing the results of various electronic devices. Table 1 lists the connection of load cell to the Arduino Board.

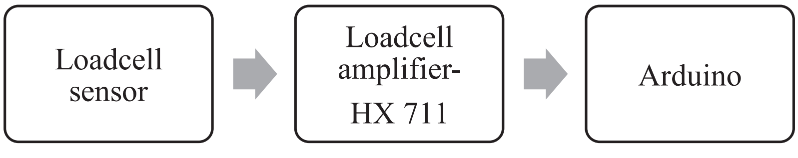


Figure 1 Flow of the load cell

Table 1 Connection of the load cell to the Arduino Board

Load Cell	HX711	HX711	Arduino
Red	E+	GND	GND
Black	E-	DT	Pin 2
White	A-	SCK	Pin 3
Green	A+	VCC	5V

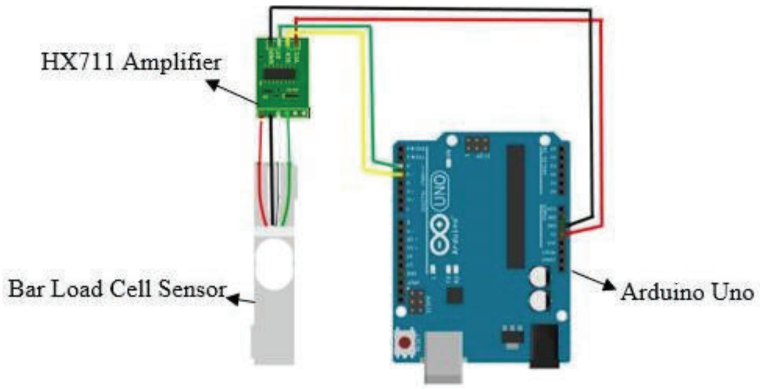


Figure 2 Connecting the Load Cell and the HX711 Amplifier to the Arduino

The basic connecting of the load cell sensor and HX711 Amplifier to the Arduino Board is shown in Figure 2. A two-wire interface communicates with the HX711 amplifier (Clock and Data). It is compatible with any digital pin on the Arduino board. There are four wires in the load cell sensor. All the wires will attach to the HX711 amplifier.

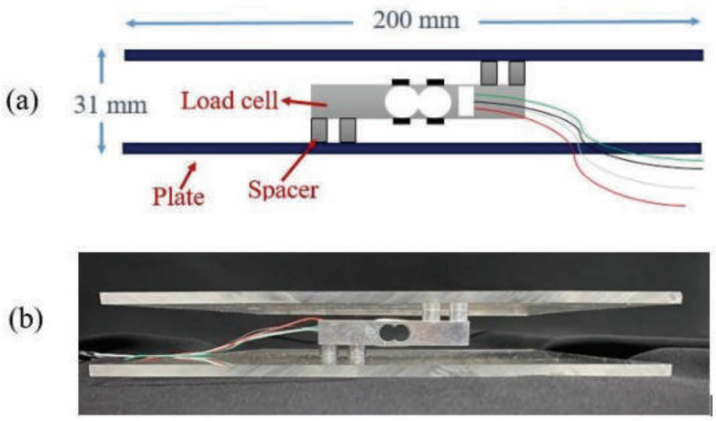


Figure 3 (a) Schematic Diagram (b) Actual

Figure **3** shows the proposed design for the sensor system positioned between two platforms in a Z formation. There are two spacers placed on each end of the bar. The acrylic plate size is 200 mm x 200 mm. An acrylic plate is used in this project. Acrylic sheet is thirty times stronger than regular glass and 50% lighter than glass.

3. Materials and methods

Materials used in this study include a 5 kg and 10 kg load cell sensor, an acrylic plate, and a data logger device.

3.1 Statistical Analysis

ANOVA is a statistical method for obtaining the appropriate components level for verifying ideal design parameters through confirmation tests. It is used as a decision-making tool to detect fluctuations in process parameters [6]. ANOVA test was used to see whether there were any significant differences between the weight and mean comparison. A p-value of < 0.05 was considered statistically significant [5].

3.2 Load Cell Test

In this experiment (Figure 4), to compare how the number of bar load cell sensors affects soil weight, two design configurations of bar-based load cell sensors with acrylic plates will be provided. The plate used for both designs were acrylic plates. Next, 9 points on each plate were marked, and the weight at each point was recorded. The data were analyzed using Analysis of variance (ANOVA).

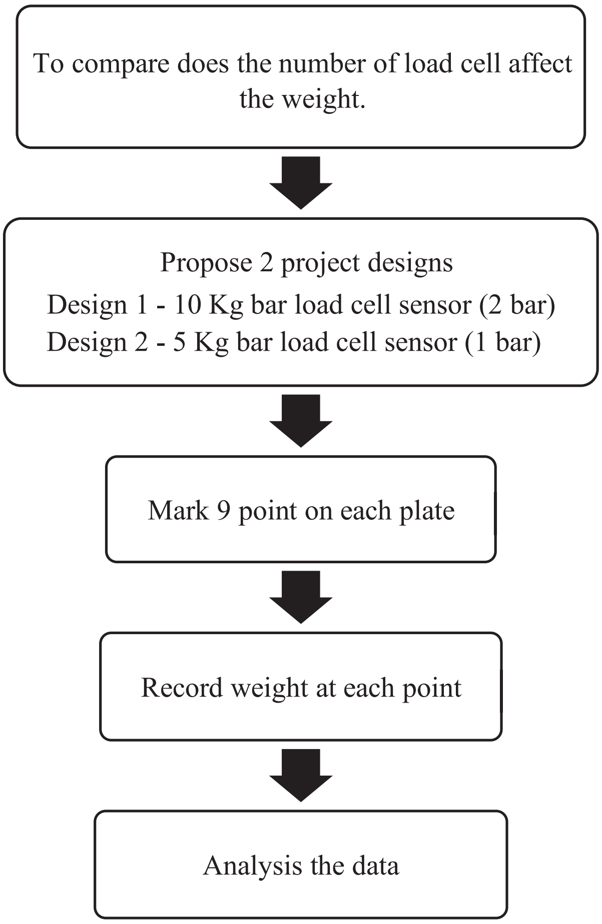
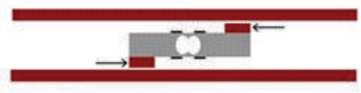
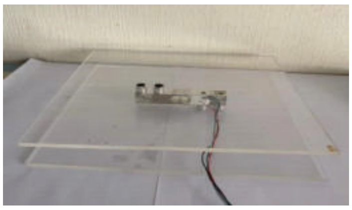
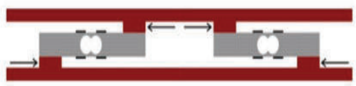
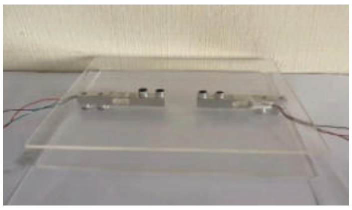


Figure 4 Experimental flow

Table 2 indicates the comparison between types of load cell sensor design in the Schematic Diagram. The size of both load cell sensors is the same.

Table 2 Schematic Diagram of Design 1 and Design 2

Design	Type of Load Cell Sensor	Schematic Diagram (Side View)	Model Design
1	10kg Bar-based load cells		
2	5kg Bar-based load cells		

For Design 1, the bar-based load cell sensor was placed at the centre of the acrylic plate. The type of load cell for Design 1 was a 10kg bar-based load cell sensor, while for Design 2, two 5 kg bar-based load cell sensors were used.

To investigate the impact of the number of bar load cell sensors on soil weight, nine spots on each plate (Figure 5) were chosen to record the weight at each position. A weight load was applied on each site, and the reading was taken. This experiment was repeated with 10 N (1.0197 kg), 20 N (2.0394 kg), 30 N (3.0591 kg), 40 N (4.0789 kg), and 50 N (5.0986 kg) weight loads.

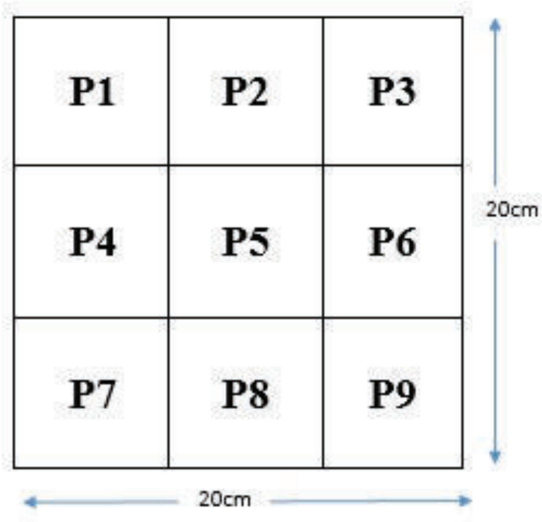


Figure 5 Nine points of each plate

3.3 Gravimetric method

The gravimetric approach is commonly used to determine soil moisture content [2]. A soil sample of known volume was oven dried for 24 hours at 105 °C [3]. Gravimetric water content (Eq.1) is the mass of water per mass of dry soil. It is calculated by weighing a sample of soil (m_w), drying the sample to remove the water, and then weighing the dried soil (m_S) [6].

$$\text{Gravimetric water content } (\theta g) = \frac{m_s}{m_w} \times 100 \quad (1)$$

Where, m_s = mass of the soil solids and m_w = mass of water.

3.4 Calibration Method

The experimental requirements (Figure 6) were five samples, and each sample had three replications. The initial soil weight of the sample was constant at 180 g. Water was added to the soil sample (0 ml, 15 ml, 30 ml, 45 ml, and 60 ml). The experimental outcome produces the GWC value. Figure 7 depicts the full design setup for Method 1. Linear regression is used to model the relationship between dependent and independent variables. Eq.2 can be used to calculate the linear regression. Calibration ensures that all equipment and sensors measure accurately [7].

$$\mathrm{Y} = mX + \mathrm{C} \quad (2)$$

Y is the dependent variable in this equation, and X is the independent variable. M, and the intercept by c represents the slope of the line.

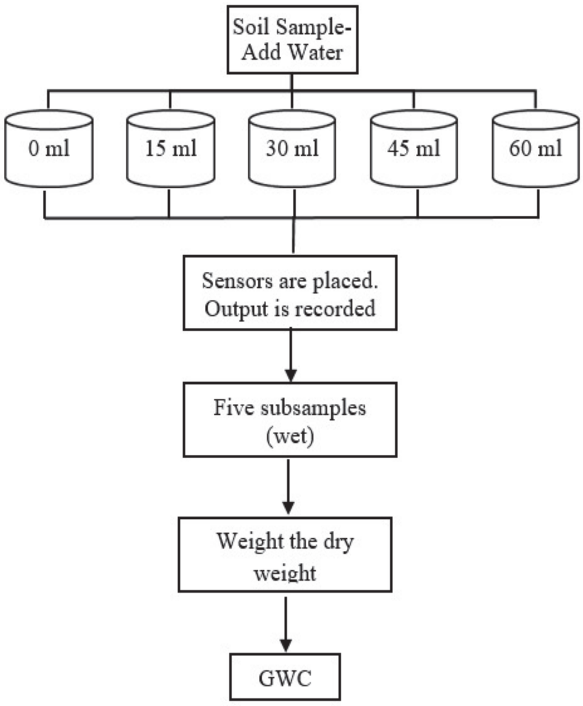


Figure 6 Experimental Design

Figure 7 Full Setup of Design 1

4. Result and discussion

4.1 Accuracy

The measurement results for each method were very similar and constant for the various point positions on the model. Figure 8 shows the comparison weight of Design 1 and Design 2 at each point.

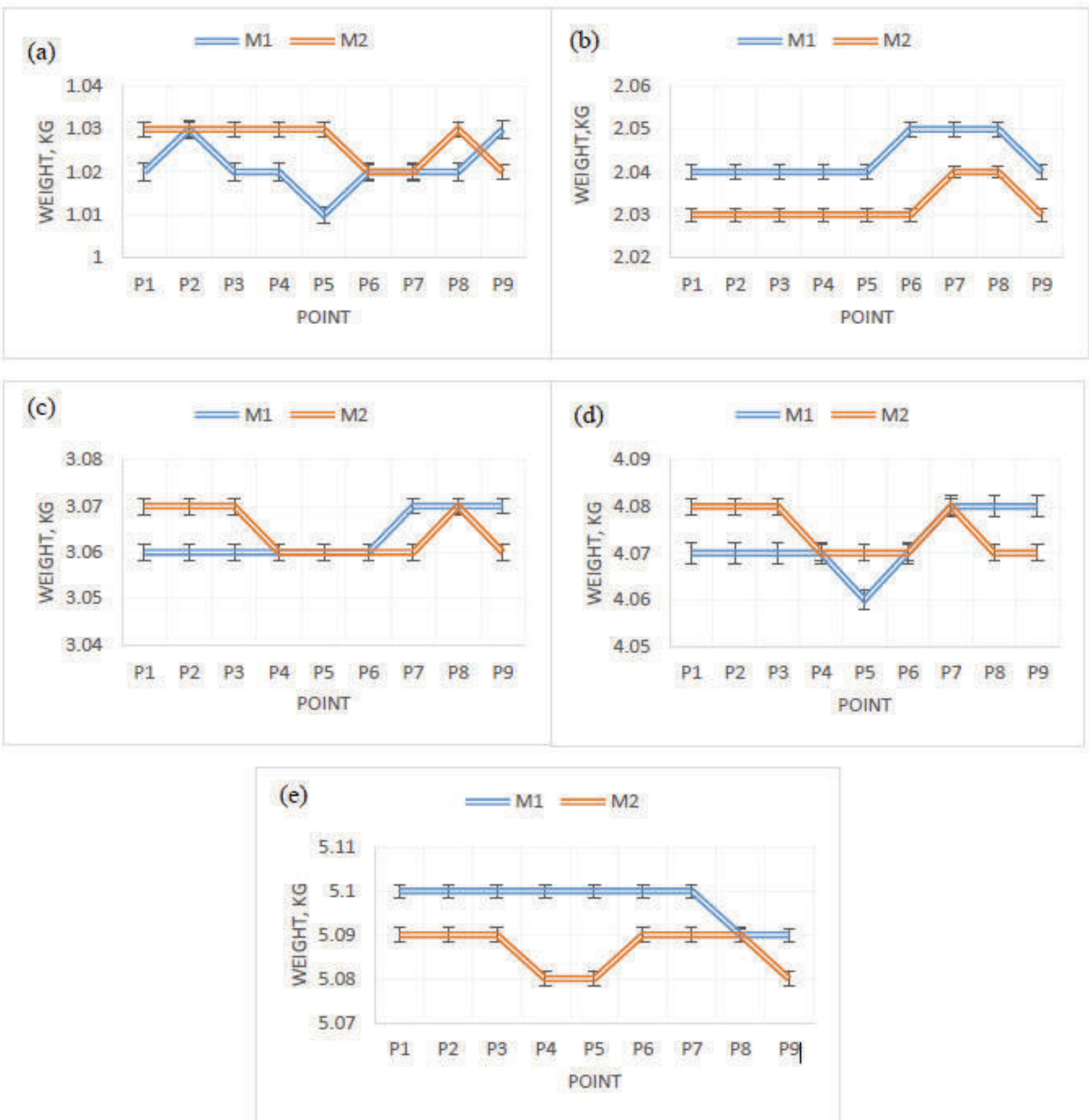


Figure 8 Graph of Weight versus Point (a) 10 N (1.0197 kg) (b) 20 N (2.0394 kg) (c) 30 N (3.0591 kg) (d) 40 N (4.0789 kg) (e) 50 N (5.0986 kg)

The sample's p-value was (p>0.05). A p-value greater than 0.05 was judged statistically insignificant [7]. Bond strength did not differ significantly between groups ($p > 0.05$). There is no difference in average soil weight between d and no difference in average soil weight between samples. The influence of one independent variable on average soil weight is independent of the other (no interaction effect). Design 1 has been chosen because it is economical compared to Design 2

4.2 Calibration

Laboratory-based soil moisture sensor calibration was performed, and the data for five different soil samples were collected using the load cell sensor-based data acquisition system. Soil samples are made by mixing an increasing array of water till the fifth container saturates. This experiment has a total of three replications. All the experimental data are plotted as shown in Figure 9.

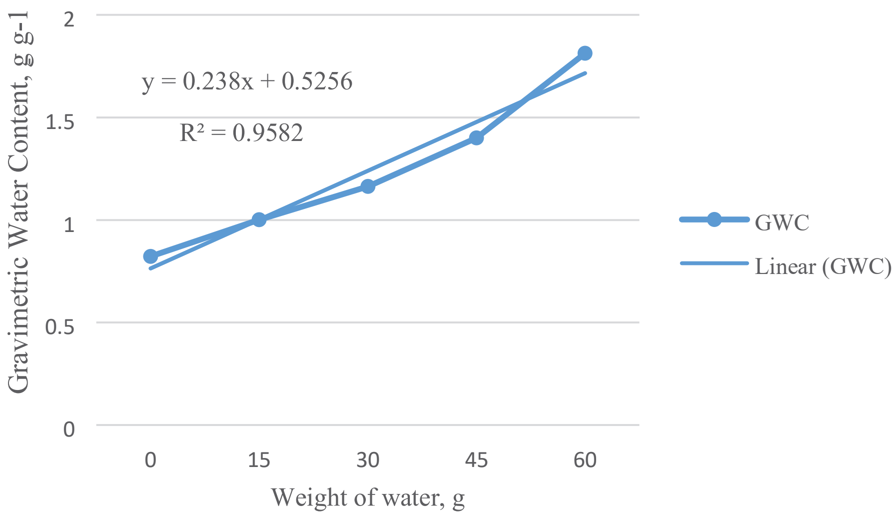


Figure 9 Graph of gravimetric water content against soil weight

The graph (Figure 9) shows the graph of Gravimetric Water Content (GWC) against soil weight for Design 1. The trend of gravimetric water content against soil moisture is increased dramatically. To allow applying interpreting regression models easier, the distribution of R^2 values is provided [8]. A high R^2 in investing, more than 85%, indicates that the performance of the stock or fund is generally consistent with the index. R^2 values were more significant than one could be considered relatively strong. The soil weight was calibrated using data at all sample, and a highly correlated relationship between Design 1($R^2 = 0.96$) was found between the measured soil weight and GWC (Figure 9). R^2 values and the calibration equation were tabulated in Table 3.

Table 3 R^2 and Calibration Equation

Sensor	Design of Experiment	R^2 Score	Calibration Equation $y = mx+c$	
			m	c
Load Cell Sensor	1	0.9649	0.0063	-0.2306
	2	0.9903	0.0085	-0.3766

5. Conclusion

The measurement results for each method were very similar and consistent for the various point positions on the model. The comparison based on the calibration and response of two low-cost soil moisture sensors is presented in this manuscript. The calibration equations for GWC are shown in Table 3. The larger the R^2 value (R^2 >0.85), the better the regression model fits this observation. The R^2 value for the graph and GWC against soil weight are higher than 0.9. The regression model provides the observation. Further, this setup can be used with load cell sensor sensors with an IoT system to estimate the soil moisture.

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