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Analysis of the Accuracy and Precision of Load Cell Sensors in IoT-Based Water Mass Measurement

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ABSTRACT

Accurate and precise mass measurement is an important aspect of sensor based measurement systems. Load cell sensor are widely used because load cell can convert mechanical load into measurable electrical signal and can be integrated with Internet of Things (IoT) system. This study aims to evaluate the characterization, accuracy, and precision of a load cell sensor in measuring water mass using an IoT-based measurement system. The research employed an engineering research approach through the design, assembly, calibration, and testing the measurement system. Characterization results indicate a linear relationship between the applied load and the ADC output, with a coefficient of determination (R^2) of approximately 0.9997. Accuracy testing was conducted using 12 variations of water mass, while precision testing was performed through 15 repeated measurement. The accuracy test resulted get an average of 97.55%. the precision test produced average measures mass of 58.90 gram and an average precision of 98.81%. the result indicate that the load cell provides relatively accurate and consistent measurement of water mass within the tested measurement range. Therefore, the load cell demonstrates good performance and is suitable for water mass measurement in an IoT-based instrumentation system.

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1. INTRODUCTION

Measurement is a crucial activity across various fields, such as designing and building of instrumentation. Getting accurate and consistent measurement results are essential for the obtained data to be usable and analyzable [1]. In mass measurement, the accuracy and precision of the instrument employed are of paramount importance. Accuracy refers to the closeness of a measured of repeated measurements under the same condition, which precision refers about how much the results still consistent even when measurement are repeated [2]. Technological progress made simpler measurement processes by using microcontroller system. A load cell sensor is a type of sensor that uses to measure the weight of an object [3]. The load cell sensor has a small analog output of only millivolts, so it requires an amplifier module to amplify the sensor’s analog signal [4]. The HX711 commonly used as an interface for load cell sensor because HX711 provides signal amplification and high-resolution analog to digital covertion, making the module suitable for microcontroller-based weighting system [5]. Load cell sensor works by turning changes in force caused the weight applied, into electrical signal that a microcontroller can read and use. Using a load cell makes measurement more easier to get digital mass data and enable automated measurement[6]. However, before a load cell in integrated into measurement system, it must undergo testing for accuracy and precision to determine its suitability for use.

Water is an ideal medium for testing mass measurement system due to its ready availability and the ease with witch it can be provided in varying masses. Measuring the mass of water using a load cell allows for the evolution of sensor performance across a range of loads [7]. Previous studies have applied Load cell sensor to measure plant water usage and monitor mass changes continuously [8]. Additionally, an IoT-based water monitoring system utilizing a load cell and an ESP32 was developed to monitor changes in water volume within a large container in real-time [9]. Recently, an IoT-based weighing system was also developed by integrating a load cell with microcontrollers and a data processing platform for real-time monitoring and validation against a reference scale [10]. This studies demonstrate the potential of load cell for water-related measurement and monitoring applications[11]. However, evaluating load cell performance requires not only monitoring changes in water mass but also quantitatively assessing measurement accuracy and repeatability. Therefore, measurements at several reference mass values and repeated measurements under the same conditions are necessary to evaluate the accuracy and precision of the sensor.

This study focuses on analyzing the extend to which a load cell can precisely and accurately measure the mass of water across various mass ranges and repeated measurements, thereby characterizing the sensor's performance when measuring water within an IoT-based system. Combining load cells with microcontrollers and IoT system can simply the process of capturing and monitoring weight data. Characterization was performed by applying various known loads and observing the ADC output generated by the load cell via an HX711 module to evaluate the linearity. The analysis was made out by providing several variations in water ass and comparing the sensor reading with the references mass values, as well as carrying out repeated measurement at certain masses to determine the consistency of the reading results. The study results are expected to provide information regarding the load cell's ability to measure water mass and serve as a basis for assessing the feasibility of its use as a mass measurement sensor in IoT-based instrumentation system.

2. MATERIAL AND METHODS

This research is categorized as engineering research, which focuses on design and testing of a internet of thing-based water mass measurement system to produce a functional product whose performance can be tested. Engineering research has several stages, starting with establishing an idea of system, make hardware assembly, integration of the load cell sensor with the microcontroller and IoT system, and testing sensor performance**.** After the tool made, it will be tested to determine the feasibility [12]. The testing was conducted to determine the accuracy and precision of the load cell in measuring water mass. This research was executed in the Electronics and Instrumentation Laboratory, Department of Physics, Faculty of Mathematics and Natural Science, Padang State University. The research period lasted from February to July 2026. The research variables consisted of independent, dependent, and controlled variables [13]. The independent is reference maa of water. The dependent variables are the measured mass, accuracy, and precision of the load cell. Meanwhile, the controlled variables include the Arduino microcontroller and the electronic components used.

The hardware design can be seen in Figure1. The hardware is designed to resemble a block-shaped scale with dimension of 17x17x5 cm. a load cell sensor is positioned in the center as the primary component for detecting changes in load. An acrylic sheet is mounted above the load cell sensor to serve as a platform or receiving surface. Additionally, a bottle is placed at one end of the device to act as water reservoir; water is then released or poured from the bottle so that the weight of the water can be detected by the load cell sensor. The load cell sensor measures force of weight web the sensor experiences pressure or strain on the metal [14]. The load cell sensor has a small analog output of only millivolts, so it requires an amplifier module to amplify the sensor's analog signal. The HX711 amplifier module is suitable because it can be connected to a microcontroller [4].

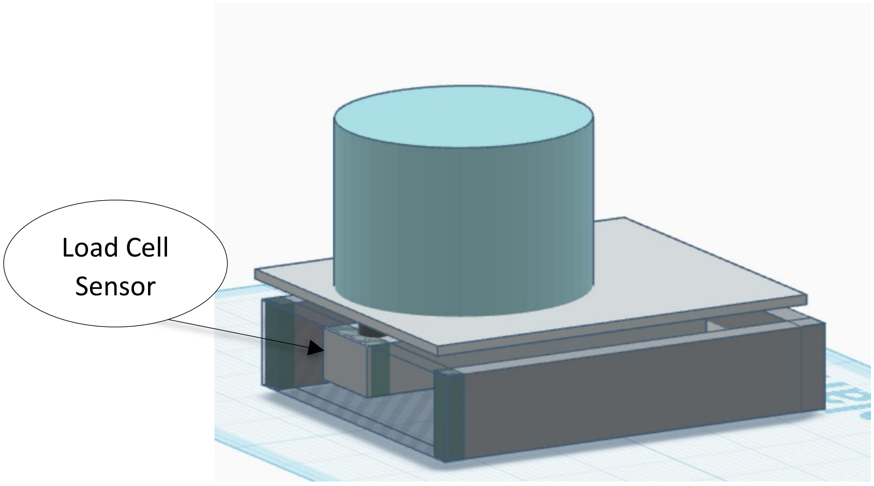

Figure 1. Hardware of load cell system

The software system was designed to acquire, process, transmit, and display water mass measurement. In software design, the system initiates when the website is opened. When water is poured into the glass, the loas cell sensor measures the weight resulting from the water. Then the measurement data is processed by an Arduino microcontroller, and the results are displayed on the webpage. The measured mass is displayed on the website in real time, allowing the measurement results to be monitored remotely. Once the process is complete, a "tare" button is available to reset the system for a new measurement. The Software design is generally defined using a flowchart. A flowchart for an IoT based remote laboratory can be seen in Figure 2.

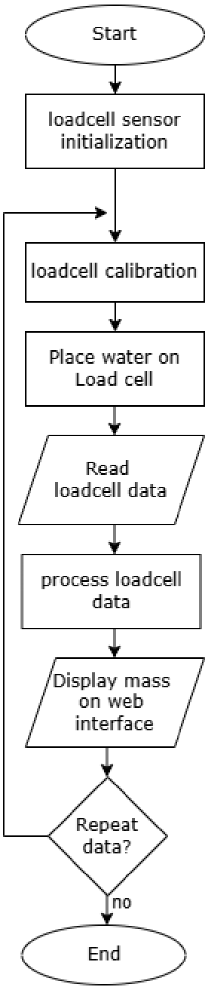

Figure 2. Flowchart of load cell measurement

The measurement procedure is to conducted in two stage; accuracy testing and precision testing of load cell sensor. Before the measurement, the measurement system in initialized, and the load cell is calibrated to ensure that sensor start from zero. Next the sensor's accuracy and precision will be compared with a standard measuring tool in the form of a scale[15]. For accuracy testing, water was provided with several predetermined reference masses. Each references mass is measured using the load cell, and the measured value displayed by the system is recorded. The measured mass is then compared with the corresponding reference mass to determine the load cell's accuracy. Testing is performance across various mass values to evaluate the sensor's response through the measurement range. The accuracy of the load cell sensor is determined by comparing the mass measured by the sensor with the reference mass obtained from the scale [16]. The accuracy is calculated using Equation 1.

$$\text{Accuracy}(\%) = \left(1 - \left|\frac{\text{Yn} - \text{Xn}}{\text{Yn}}\right|\right) \times 100\% \tag{1}$$

Where Yn is the reference mass measured using the scale and Xn is the mass measured by load cell sensor[17]. The higher accuracy percentage indicates that the measured mass is closer to the reference mass [18]. In addition accuracy, the measurement error is calculated to determine the deviation between the load cell measurement and the reference mass. Measurement error is defined as the difference between the measured quantity value and the reference quantity value [16]. The absolute percentage error is calculated using Equation 2.

$$\text{Error }(\%) = \left|\frac{\text{X}_\text{n} - \text{Y}_\text{n}}{\text{Y}_\text{n}}\right| \times 100 \tag{2}$$

Where (X_n) is the mass measured by the load cell sensor and (Y_n) is the reference mass measured using the scale. For the precision test, a predetermined mass of water is measured repeatedly under identical condition. The result of each measurement is recorded and used to determine the consistency of the load cell readings. The mean value and variation of these repeated measurements are analyzed to evaluate the sensor's precision. The sensor precision is expressed in Equation 3.

$$\text{Precision }(\%) = 1 - \left|\frac{X_i - \overline{\text{X}}}{\overline{\text{X}}}\right| \times 100\% \tag{3}$$

Where X_i represents each repeated measurement and $\overline{X}$ represents the mean values of all repeated measurement. A higher precision percentage indicates that the repeated measurement are more consistent with the mean value [16]. The measurement data obtained from both test will be analyzed quantitatively using appropriate equation. Accuracy is determined by comparing the measured mass to the reference mass, whereas precision is determined based on the consistency of repeated measurements at the same reference mass.

3. RESULTS AND DISCUSSION

To evaluate the use of the load cell sensor, repeated measurement of water mass were conducted. The result obtained are discussed to demonstrate the effectiveness of the load cell sensor in measuring water weight. The physical appearance of the IoT-based water mass measurement system is shown in Figure 3.

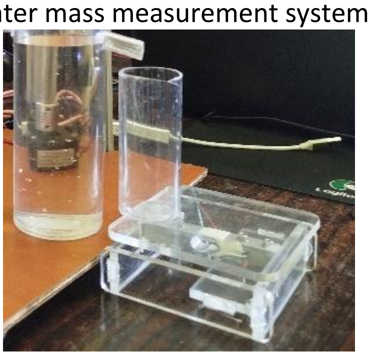

Figure 3. hardware load cell system

The figure is annotated to identify the main components of measurement system, including the measurement container, load cell sensor, and electronic measurement unit. The measurement container is placed directly on the load cell sensor, which functions as the main sensing element for detecting changes in the mass of water. The load cell is connected to the electronic measurement unit to process the sensor output and convert the detected load into a mass value. The resulting measurement data can then be monitored through the IoT-based system.

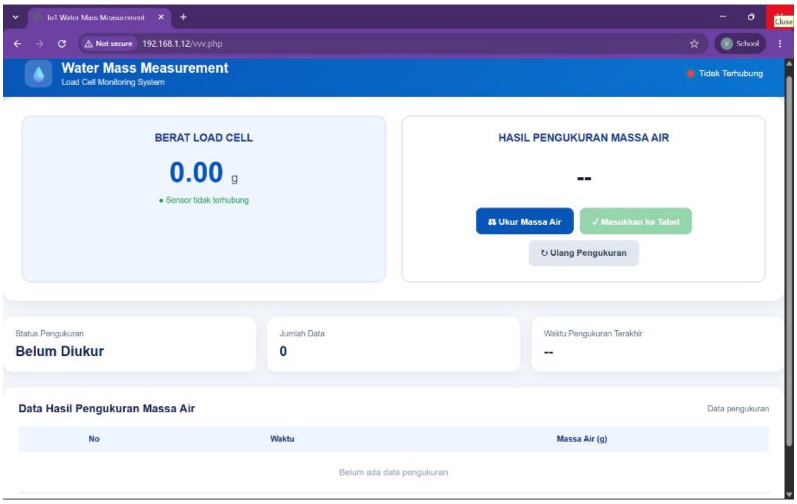

Figure 4. IoT-based web interface for water mass measurement

Figure 4 illustrates the developed software system, which provides a web-based interface for displaying and logging water mass measurement data. The website is designed ro receive measurement data from a load cell via a microcontroller and display sensor readings in real-time. The web interface comprises a real-time load cell weight display, a measurement control section, a measurement results panel, and a data table for recording the obtained measurement. This interface enables the monitoring of the measurement process without the need to observe the sensor output directly from the microcontroller.

3.1. Load Cell Sensor Characteristics

The characterization was conducted to determine the sensor’s response to varying applied loads and to established the relationship between the actual water mass and the sensor output. Characterization is necessary because the load cell does not produce a mass value directly, the load cell produces a very small voltage signal (microvolts-millivolts) due to changes in the resistance of the strain gauge, then this signal is amplified and converted by the ADC into digital data, that represent the magnitude of the force or mass [19]. Characterization applied masses ranged from 10 to 150 gram, and the corresponding ADC values were recorded for each load variation.

Table 1. Load cell sensor characterization

Trial-n	Reference Mass (gr)	ADC
1	4.4	4330
2	10.3	9730
3	16.3	15773
4	19.7	19461
5	23.4	23248
6	28.9	28685
7	33.6	33177

8	38.6	38134
9	43.8	44055
10	49	49137
11	55.6	55692
12	59.9	60805
13	67.1	608008
14	72.7	73365
15	76.9	77762

Table 1 show the ADC output obtained from the load cell for various applied load masses. The results show that the ADC output increases consistently as the load mass increases. This gradual rise in ADC output indicates that the load cell throughout the testing range. Such variations can arise from the characteristic of the load cell as well as the electronic signal conversion process through the HX711 module. The result obtained provide the initial sensor response data necessary for further analysis of the relationship between load mass and ADC output.

Figure 5 illustrates the relationship between load mass and the ADC output from the load cell. The plotted data reveals an increasing and generally linear relationship, implying that the applied load within the testing range. Linear regression analysis yielded a coefficient of determination (R^2) o approximately 0.9997, meaning that most of the variation in sensor output can be explained by changes in the mass of the applied load. Therefore, the characterization results show that load cell provides a consistent and fairly linear response over the tested measurement range, making it suitable for use for measurement.

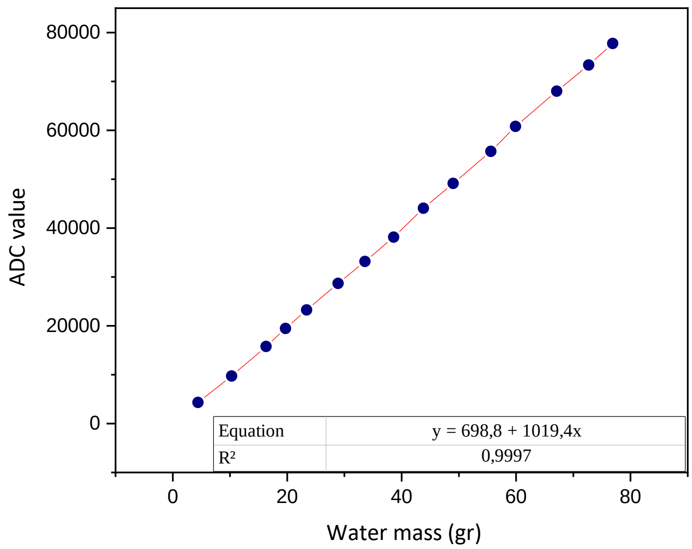

Figure 5. Graph of ADC load cell sensor versus the scale

3.2. Accuracy of Water Mass Measurement

The accuracy test was conducted to evaluate the ability of the load cell sensor to produce measurement results that were close to the reference mass of water. The test was performed using 12 variations of water mass, with reference masses ranging from 3.8 gram to 73.3 gram. The measures values contained from the load cell were compared with the reference masses, and the measurement error and accuracy will be calculated.

Table 2. Load cell sensor accuracy and error data

Trial-n	Reference Mass (gr)	Load Cell (gr)	Error (%)	Accuracy (%)
1	3.8	03.56	6.31	93.68
2	9.2	8.98	2.40	97.60
3	14.3	13.86	3.07	96.92
4	17.9	17.48	2.34	97.65
5	24.7	24.55	0.60	99.39
6	28.9	28.32	2.00	97.99
7	33.6	32.84	2.26	97.73
8	41.9	40.72	2.81	97.18
9	48.4	47.4	2.06	97.93
10	53.2	52.14	1.99	98.00
11	63.4	62.41	1.56	98.43
12	73.3	71.92	1.88	98.11

Table 2 show the result of load cell measurement values relatively close to the reference masses across the tested range. The highest error was 6.31% at a reference mass of 3.8 gram, corresponding to an accuracy of 93.68%. in contrast, the lowest measurement error was 0.60% at a reference mass of 24.7 gram, resulting in the highest accuracy of 99.39%. overall, the accuracy values ranged from 93% to 99%.

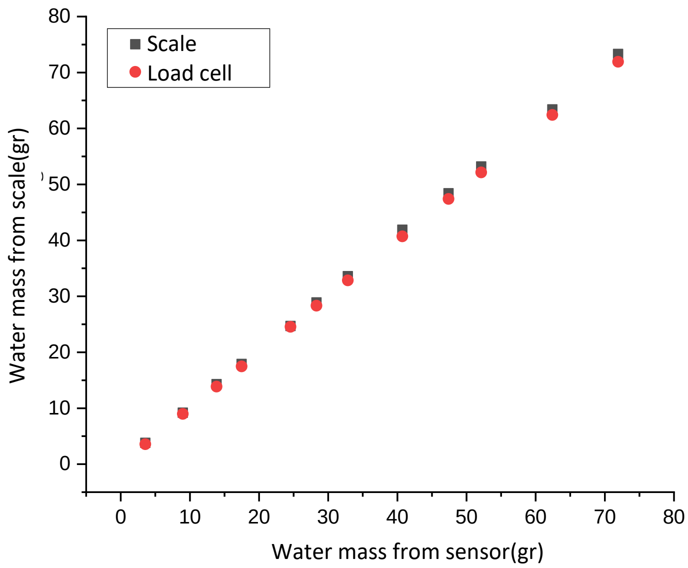

Figure 6. Graph of load cell sensor accuracy versus the scale

Figure 6 shows that the load cell measurement values follow the increasing of the reference mass. The measurement values are consistently slightly lower than the reference values, indicating a tendency toward underestimation throughout the tested measurement range. The largest difference occurs at the lowest reference mass, while the difference becomes relatively smaller at higher masses.

The relatively larger error observed at the lowest measurement mass indicates that the measurement deviation was more noticeable when the measured mass was small. As the reference mass increased, the measurement error generally became smaller, although some variations were still observed. This indicates that the load cell was able to provide measurement results that were close to the reference values over the tested measurement range.

3.3. Precision of Water Mass Measurement

The precision test was conducted to evaluate the consistency of the load cell measurement when measuring the same water mass repeatedly under identical measurement condition. A reference water mass of 59.6 gram was used, and the measurement was repeated 15 times. The results of the precision test are presented in table 3.

Table 3. Load cell sensor Precision data

Trial-n	Load Cell (gr)	Precision (%)
1	58,94	98.88
2	58.72	98.50
3	58.89	98.79
4	58.92	98.84
5	58.99	98.96
6	58.68	98.74
7	59.13	99.20
8	59.11	99.17
9	58.96	98.91
10	58.82	98.67
11	58.78	98.60
12	58.65	98.38
13	58.87	98.76
14	58.92	98.84
15	58.99	98.96
Average	58.90	98.81

The measurement results show that load cell produced relatively consistent readings during the 15 repeated measurements. The measured values ranged from 58.65 gram to 59.13 gram, while the average measured mass was 58.90 gram. The difference between the highest and the lowest measured values was only 0.45 gram, indicating a relatively mass variation in the repeated measurements. The measurement result fluctuate within a narrow range around the measured average shown in Figure 6. although none of the repeated measurement reached the reference value of 59.6 gram, the readings remained relatively close to one another. The highest measured value was 59.13 gram and the lowest value was 58.65 gram.

This relatively narrow measurement range indicates that the load cell produced consistent reading when the same water mass was measured repeatedly.

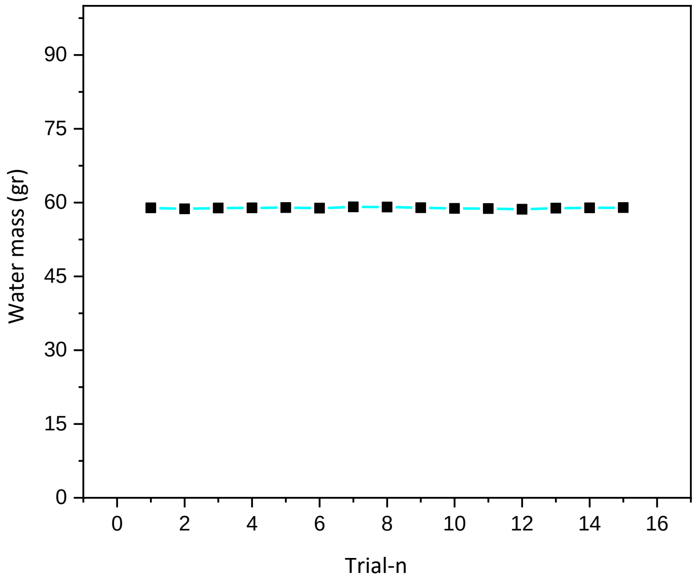

Figure 7. Graph of load cell sensor precision versus the scale

The results indicate that the load cell was able to maintain a consistent measurement response when measuring the same water mass. The relatively small variation among the 15 measurements supports the capability of the sensor to provide repeatable measurement results. The average precision obtained in this study was 98.81%, indicating that the repeated measurements were relatively consistent. However, the difference between the average measured mass and the reference mass also indicates that precision and accuracy represent different characteristics of measurement performance. In this case, the measurements were relatively consistent with each other, while their values remained slightly below the reference mass.

The precision obtained in this study is comparable to previous research using load cell sensors for mass measurement. Saputra et al. [20] reported an average precision of 99.98% and an average accuracy of 99.25% in an Arduino-base digital weighing system using a load cell sensor. The results show slightly higher precision and accuracy than those obtained in this study. The difference may be related to differences in the measurement setup, load characteristics, calibration process, and measurement range. Therefore, these finding confirm that the load cell is capable of producing repeatable measurements, although further optimization of the calibration and additional adjustments are required to improve the accuracy.

3 CONCLUSION

The result of the study demonstrate that the load cell sensor provides a consistent response to load variation applied during characterization testing. The sensor's ADC output relative to water mass gives a linear relationship, with a coefficient of determination (R^2) of approximately 0.9997. these results indicate that the load cell provides a good and consistent response within the tested measurement range. Regarding measurement accuracy, the load cell sensor is capable of measuring water mass with good accuracy values ranging from 93.68% to 99.39%, with an average accuracy of 98.11%. the measurement error ranged from 0.60% to 6.31%, indicating that the measured values were relatively close to the reference masses. For the precision, with mass of 58.90 gram, load cell sensor given the measure values ranged from 58.65 gram to 59.13 gram, with an average measured mass of 58.90 gram and an average precision of 98.81%. the relatively small variation among the repeated measurement indicates that the load cell produced consistent measurement results. Load cell sensor has demonstrated good accuracy and precision for water mass measurement within the tested measurement range. The findings indicate that the load cell can be used as a mass measurement sensor in an IoT-bases instrumentation system.

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DECLARATIONS

Authorship contribution

Vina Rahma Yeni: Conceptualization, methodology, formal analysis, software and writing-original draft.
Asrizal, and Mona Berlian Sari: Validation, Writing-review and editing.

Competing Interest

The author **declare** no conflict of interest in this study.

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Ethical Clearance

There are no human subjects in this manuscript, and informed consent is not applicable.

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