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Design and Development of a Low-Cost Fuel Consumption Meter for the Performance Testing of Agricultural Machinery

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ABSTRACT

The fuel consumption of an engine is an essential parameter that needs to be measured during the testing of an agricultural machinery. Commercially available fuel meters are expensive. The purpose of the study is to develop a fuel meter with data logging capabilities using inexpensive materials. The developed fuel meter follows the gravimetric principle in which the initial and final weights of the fuel after a specified amount time has elapsed are obtained and used to calculate the fuel consumption. The main components were the Arduino UNO microcontroller, data logging shield, and a load cell sensor. It was calibrated for diesel and gasoline fuels during the actual testing of different agricultural machinery such as centrifugal pumps, small engines, two-wheel tractors, and four-wheel tractors. Data were compared to the existing fuel meter and calibration curves were generated. Separate tanks were used for both the gasoline and diesel fuel to avoid mixing of fuels and damaging the engine. The generated equations for diesel fuel ($y = 1.0957x – 0.0962$) and for gasoline fuel ($y = 0.8551x – 0.0017$) were implemented in the Arduino code. A paired T-test was conducted and it showed that at a 5% level of significance, there is no significant variation in the data before calibration ($p= 0.054$) and after calibration ($p= 0.550$) for diesel fuel. While at a 5% level of significance, there is a significant variation in the data before calibration ($p=1.03e^{-8}$) for gasoline fuel but showed no significant variation after calibration ($p=0.610$). In comparison to the existing fuel meter (Ono Sokki FX-1100 Series), the percent difference obtained before calibration ranges from 1.05% to 27.12%, and after calibration ranges from 0% to 6.39% for diesel fuel. The percent difference obtained before calibration ranges from 10.18% to 19.96% and 2.03% to 9.40% after calibration for gasoline fuel in comparison to the volumetric method fuel meter of AMTEC. After performing calibration and statistical analysis, the developed fuel meter can be considered as good as the existing fuel meters of AMTEC. The researchers recommend to provide dampers to isolate the vibration that affects weight measurement during testing or use a different sensor like an inline flow sensor to eliminate this problem. The inline flow sensor also allows the design of the fuel meter to be simpler and it will be easier to transport and use during field testing of agricultural machinery. An inline flow sensor with a wide range of capacity would be applicable for testing of agricultural machinery.

Keywords: *fuel consumption, gravimetric, low-cost, agricultural machinery, AMTEC*

INTRODUCTION

Engine is the most common prime mover used by any agricultural machinery. Fuel consumption is one of the parameters being measured during the performance testing of agricultural machinery There are several methods of measuring fuel consumption such as the gravimetric method, volumetric method, differential-pressure method, and paddlewheel method. There are commercially-available fuel consumption meters that employ one of the aforementioned methods but a single fuel meter may cost as much as a million pesos, which prompted the researchers to design and fabricate a fuel consumption meter that would only cost around Php 500,000. The Agricultural Machinery Testing and Evaluation Center (AMTEC) is the premier reference testing center of agricultural and fisheries machineries in the country after the enactment of the RA10601 or “AFMech Law” in 2013. The AMTEC tests different agricultural machinery such as small engines, pumps, two- and four-wheel tractors, etc. Most of these machinery uses an engine as prime mover.

The gravimetric method is one of the most common and simplest methods of measuring fuel consumption. This method requires measuring the initial weight and final weight of the fuel after running a machine for specified time, then multiplying the weight difference to the density of the fuel used. In the study of Aravind *et al.* (2018), a load cell was used to measure the fuel level during the fuel filling process on a vehicle. The load cell is connected to an HX711 signal amplifier (based on Avia Semiconductor’s patented technology) to regulate the voltage level which resulted to a high level of weight measurement accuracy. The system is also equipped with a Global System for Mobile communication (GSM) and Global Positioning System (GPS) module to alert the user regarding measured fuel weight as well as the location. The process flow chart of the system is shown in **Figure 1**.

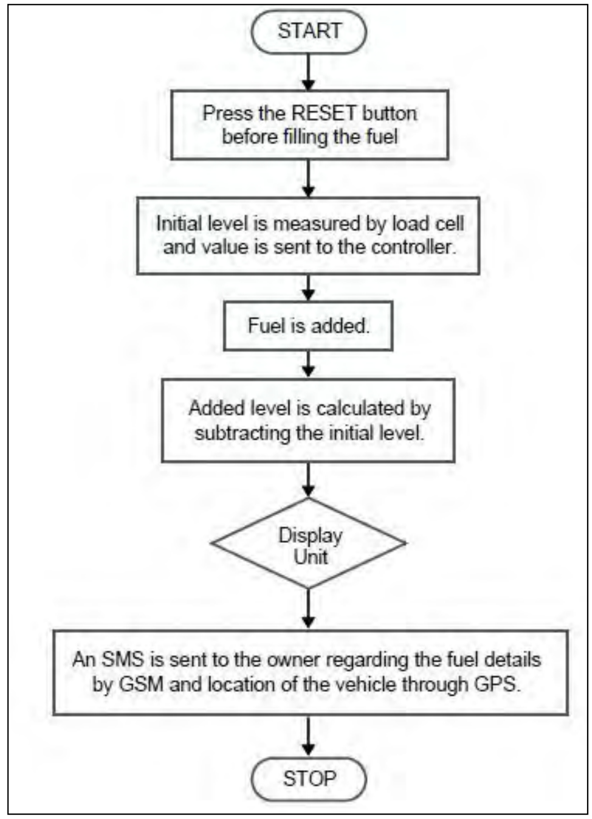


Figure 1. Process flow chart of the fuel level measurement system.

In a study by Duarte *et al.* (2018), a fuel measurement system based on the gravimetric principle for applications in the engine test bench was implemented. A minimum and maximum set point were established which signals the start and end of the measurement cycle once these points were reached. The setup also features an HX711 module load cell transmitter, which is used to amplify the signal coming from the load cell and allows the communication of the sensors with the Arduino UNO. The Arduino is in charge of the logical communication between the computer, the relay, and the scale. The diagram of the setup is shown in **Figure 2**. Lastly, the LabView computation tool was used to create a program with a user interface to display the measured fuel consumption.

Another method in measuring fuel consumption is through the volumetric method, where it relies on determining the volume of fuel consumed by an engine. Volumetric measurement uses flow devices equipped with different measuring means of various construction such as gear pumps, where the volume of fuel consumed is determined by the number of gear rotations (Taubert and Majerczyk, 2013).

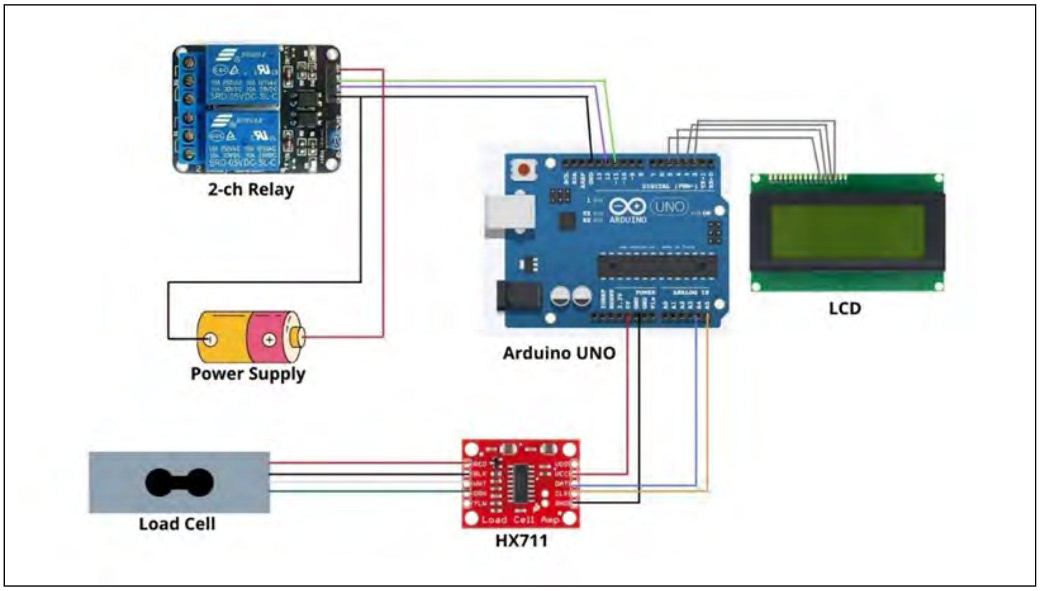


Figure 2. Wiring diagram of the fuel measurement setup.

Additionally, according to Hudson *et al.* (1993), the volumetric method is the simplest way to estimate small flows through direct measurement of the time to fill a container of a known volume. The next method is by differential-pressure, according to Sparks (2013), the use of differential-pressure sensors follows the principle of Bernoulli's law, wherein the pressure drop or the flow rate is proportional to the square root of the differential pressure. The higher the pressure drop, the higher is the flow rate.

Lastly, the paddlewheel method uses a magnet and a paddlewheel to measure flow. The force from the fluid spins the paddlewheel which makes it possible for the sensor to measure the flow based on the number of revolutions the paddlewheel makes. The magnet attached at the axis of rotation produces pulses that can be extracted as signals. These signals will convert the number of revolutions into flow rate (ES Systems, 2020). The common sensor that uses a paddlewheel is an inline flow sensor. Hapsari *et al.* (2021), used an inline flow sensor to determine the real-time fuel consumption of an engine. The system used was equipped with the Internet of Things (IoT) , where it allows the real -time transmission of data through the internet network with the need for human-to-human or human-to-computer interaction. This study used the YF-S201 flow sensor (**Figure 3**) which does not need to be under high pressure to work just like a load cell sensor but the inline flow sensor is solely dependent on gravity to function. A level sensor (HC-SR04) was also used to measure the fluid level inside the tank and calculate the volume.

The system consists of two tanks with separate level sensors with the flow sensor connected to the second tank. A GPS module, temperature and humidity sensor, and Wi-Fi module were also parts of the system and were connected to the Arduino MEGA microcontroller. The output data was uploaded to the IoT cloud via the Wi-Fi module which the user can access through the IoT website. ThinkSpeak is the IoT website used to monitor the online system (**Figure 4**).

AMTEC also has a version of the volumetric fuel meter (Ono Sokki FC-024) that uses several graduated pipettes (**Figure 5**). The volumes of the pipettes range from 10 mL to 400 mL and this fuel meter is used mostly for the testing of small engines. After the required volume is selected, the start button is pressed to measure the duration of fuel consumption. The time (seconds) is shown in the screen of the controller (**Figure 6**) but these data has to be manually recorded by the test engineer. This model of fuel consumption meter has been already phased out.

Figure 3. YF-S201 flow sensor (left) and HC-SR04 level sensor (right).

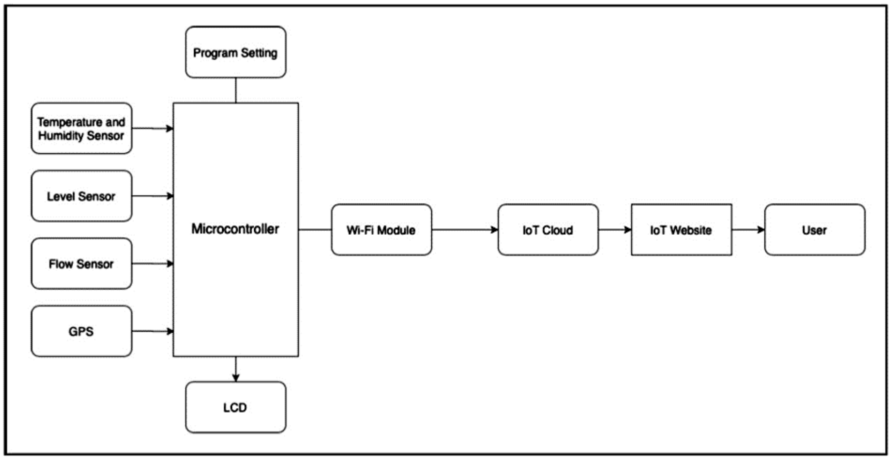


Figure 4. Schematic diagram of the real-time fuel measurement with IoT.

Figure 5. Ono Sokki FC-024 fuel consumption meter of AMTEC.

Figure 6. Controller of the Ono Sokki FC-024 fuel consumption meter of AMTEC.

Another fuel consumption meter in AMTEC uses the differential-pressure method. The differential-pressure fuel meter is mostly used for the testing of four-wheel tractors. In this method, the fuel consumption is measured automatically but the test engineer still records the data manually. This fuel meter is a mass burette flow detector (Ono Sokki FX-1100 Series) (**Figure 7**) paired with a digital flowmeter (Ono Sokki FM-3100). The principle of detection is when the fluid inside the tank goes below a certain level (L3), a signal is sent to open the electromagnetic valve to allow more fluid to enter. When another level (L2) is reached, the valve closes and after about two (2) seconds, the device starts to measure the instantaneous flow (Ono Sokki, 1997). This type of fuel consumption meter is relatively expensive. The latest unit procured by AMTEC cost about PhP1.348Million (around $24,500 as of July, 2022).

Lastly, the AMTEC also fabricated their own version of a volumetric fuel consumption meter (AMTEC FM-01) which is fully mechanical and manually-operated. The fuel meter (**Figure 8**) is composed of a fuel tank, 10 mL burette, switches, gate valve, solenoid valve, and a chemical hose. The principle of operation is by determining the amount of time (in seconds) it takes to consume the fixed 10 mL volume of fuel. The outlet of the fuel meter is connected to the injection pump of the engine using a chemical hose. During operation, the engine is being supplied with fuel from the fuel tank, and when the fuel consumption is being measured, the switches are pressed then the solenoid valve gets activated making and the 10 mL burette as the fuel source. The time it takes to consume the 10 mL fuel is obtained using a stopwatch and manually recorded. The switches are pressed again to deactivate the solenoid valve and reverts the fuel source to the fuel tank.

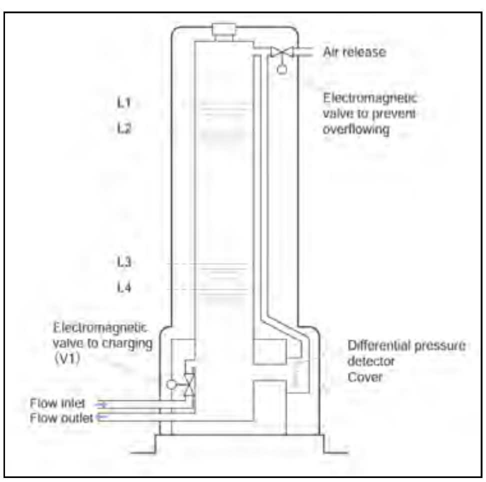


Figure 7. Mass burette flow detector.
Source: (Ono Sokki Co., Ltd., 1997)

Figure 8. AMTEC FM-01 fuel consumption meter.

The existing fuel meters of AMTEC are either purely mechanical and manually-operated or the commercially-available fuel meters that are expensive. The data from these fuel meters are still manually recorded. This study aimed to design and develop a low-cost fuel consumption meter, for both gasoline and diesel fuels, for performance testing of agricultural machinery. Specifically, the developed fuel meter must have the capability to automatically store and record data.

METHODOLOGY

Design of Fuel Consumption Meter

Several criteria were considered in designing the fuel consumption meter. The overall cost of the fuel meter must be no more than Php 500,000. Materials that were available in AMTEC were also utilized and all others had to be procured locally to avoid any additional costs from purchasing internationally. The fuel meter must be simple, easy to fabricate, calibrate, troubleshoot, and operate. It must also have simple controls and easy to install in the test setup. Lastly, the accuracy of the fuel meter based on the computed percent difference must be acceptable in comparison with the existing fuel meters of AMTEC.

The gravimetric method was selected for the design and development of a fuel consumption meter. This method utilizes load cell to determine fuel weight. Load cells are readily available in the market since these are also used as sensors for digital weighing scales. The load cell used was bought from e-Gizmo Mechatronix Central, it is a beam-type with a capacity of 40 kg. The load cell is paired with a HX711 signal amplifier as shown in **Figure 9**. The amplifier uses the HX711 7916042f chip which is based on Avia Semiconductor's patented technology (Avia Semiconductor, n.d.). It is a breakout board that regulates the voltage (5V) and amplifies the signal from the load cell for a high level of measurement accuracy. The amplifier is specifically designed for weigh scales and industrial process control. One side of the amplifier is connected to the load cell and the other side is connected to the microcontroller. The communication between the amplifier and the microcontroller uses a two-wire interface, clock (CLK) and data (DAT).

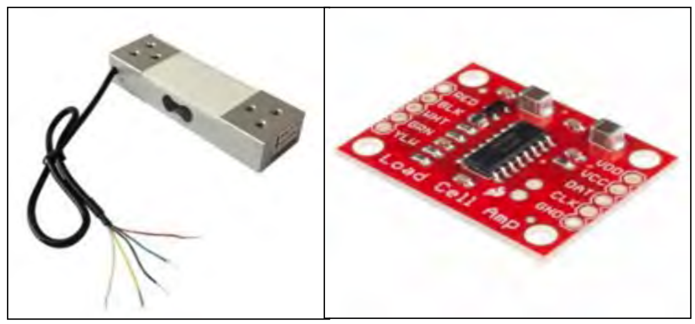


Figure 9. Load cell (left) and HX711 signal amplifier (right).

An Arduino microcontroller and a data logging shield were used for the data acquisition of the fuel meter. Push buttons were used to reset the Arduino, start the measuring of fuel consumption, and setting of tare weight. The Arduino UNO (**Figure 10**) is the most common kind of microcontroller used in electronics and coding. It is considered to be the most robust board that the user can start playing with. This board is based on ATmega328P, has 14 digital input/output pins (6 pins are for PWM), six (6) analog inputs, a power jack, an ICSP header, and a reset button.

The data logging shield used is the Adafruit Data Logger Shield (**Figure 11**) manufactured by Adafruit Industries in the US. It has an SD card interface that works with FAT16 and FAT32 formatted cards. A 3.3V level shifter to prevent damage to the SD card and allow faster reading and writing of data. The shield is also equipped with a real-time clock (RTC) to keep time going even when

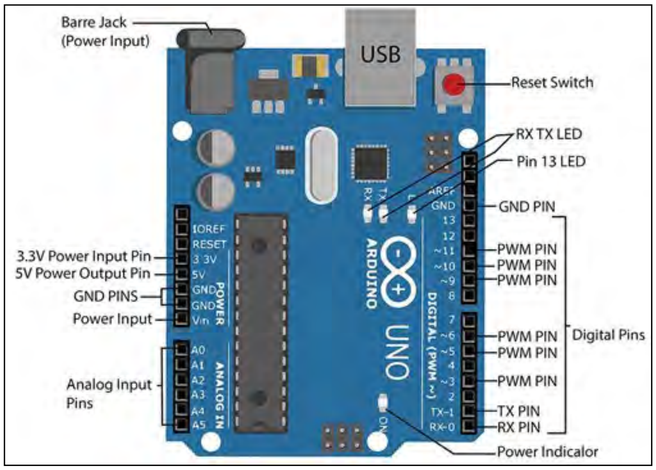


Figure 10. Arduino UNO board.

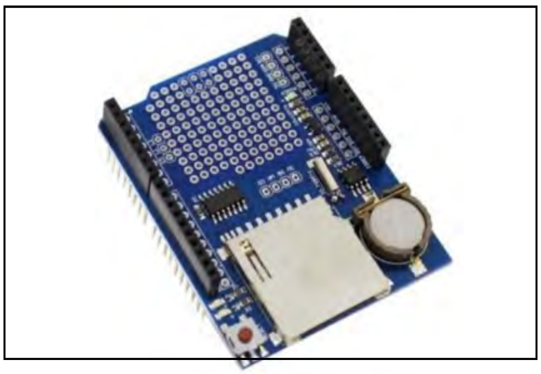


Figure 11. Adafruit Data Logging Shield.

the Arduino is unplugged. A prototyping area in the middle section of the board is also available, this allows the user to customize the shield by soldering connectors, circuits, and sensors of their choice. It uses an "R3 layout" I^2C which makes it compatible with a wide variety of Arduinos and Arduino-compatibles. The I^2C is a type of serial communication that uses a clock line (SCL) and a data line (SDA) to transfer information (Gammon, 2011). The "R3 layout" basically means it follows the R3 pinout of the Arduino UNO board.

A normally open solenoid valve (**Figure 12**) was also integrated into the system to allow the refilling of the fuel from the refilling tank to the measuring tank. Since the Arduino UNO can only handle up to 12V and the solenoid valve has an input voltage requirement of 24V, a relay module (**Figure 13**) was used to properly regulate the voltage and avoid damaging the Arduino and other electrical components. The HL-52S relay module was used, it is a low level 5V 2-channel relay interface board. It has high-current relays that can handle AC250V, 10A or DC30V, 10A. It also has a standard interface that can be directly controlled by a microcontroller. For safety requirement, the module is optically isolated from high voltage and also prevent ground loop when interfaced with a microcontroller (Handson Technology, n.d.).

Figure 12. Normally open solenoid valve.

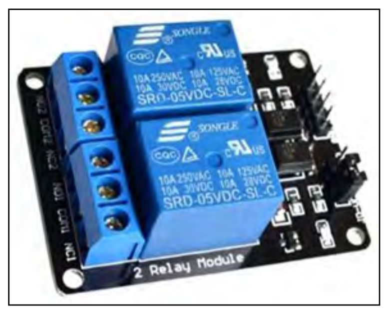


Figure 13. 2-channel HL-52S relay module.

The wiring diagram for the control of the fuel meter is shown in **Figure 14**. The relay module controls the solenoid valve and is triggered by the Arduino. The HX711 signal amplifier amplifies the low signal coming from the load cell and these signals are processed by the Arduino. A 4×20 LCD screen was used to display information such as initial weight, final weight, timer, and computed fuel consumption. The LED light turns ON during measuring of the fuel consumption and it automatically turns OFF after measurement is completed. The Adafruit datalogging shield is connected on top of the

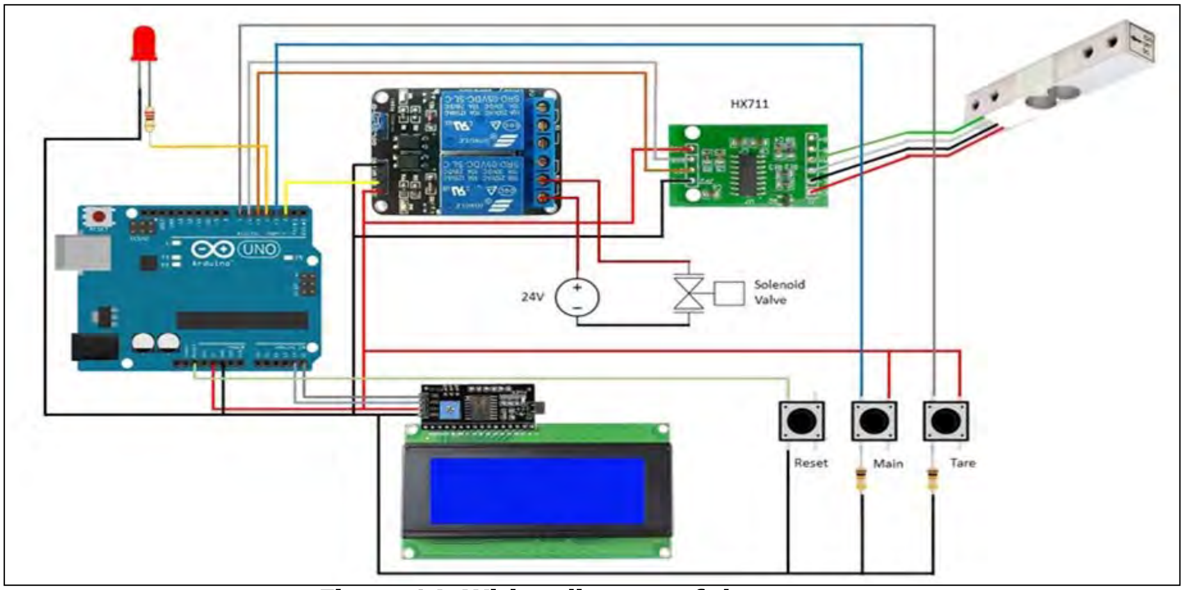


Figure 14. Wiring diagram of the system.

Arduino board as shown in **Figure 15**. The data coming from the Arduino is automatically recorded and stored in the SD card. The system is programmed to display an error message on the LCD screen saying "SD card not found" if there is no SD card detected. Once detected, the program will proceed to the screen that displays the weight, time, and calculated fuel consumption.

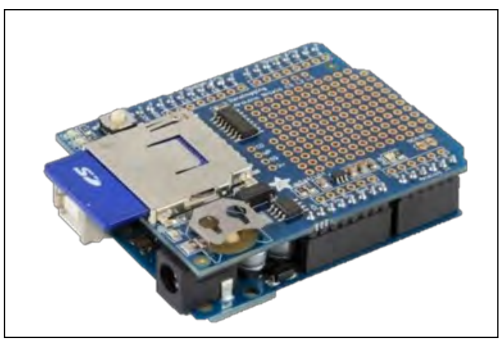


Figure 15. Connection between the Adafruit Datalogging shield and Arduino UNO board.

The fabricated fuel meter is shown in **Figure 16**. The material used to fabricate the main frame of the developed fuel meter was angle bars and sheet metal was used to fabricate the fuel tanks. The whole set up has a dimension of 406 mm × 406 mm × 2108 mm. A clear chemical hose was used to deliver the fuel from the tank to the prime mover. The fuel consumption meter has two (2) fuel tanks. The top is a reserve tank of fuel while the bottom tank is used for the measurement of fuel consumption. The load cell is located below the bottom tank. The HX711 amplifier sensor and the Arduino microcontroller which are all inside the black box. The black box is equipped with an LCD that shows the initial weight, final weight, timer, and computed fuel consumption. The black box has three (3) push buttons. The first button is the Reset button which will reset the Arduino if it encounters an error. The second button is the Main (measure) button, which when pressed will run the program for thirty (30) seconds and the fuel consumption is automatically measured and displayed on the LCD screen, and the data is also automatically recorded on an SD card. The third button is the Tare button,

Figure 16. The developed fuel consumption meter.

which when pressed, will reset the value of weight to zero. After testing, the data saved (Excel format) on the SD card can be retrieved using a computer.

Calibration of the Developed Fuel Consumption Meter

The fuel consumption meter was calibrated for both diesel and gasoline fuel, but separate tanks were used to avoid mixing fuels and damaging the prime mover during testing. The Arduino code for the diesel and gasoline fuel were separate files. The user first needs to upload the code of choice to the Arduino before proceeding in using the fuel meter. The fuel return for the diesel engine was not considered in the design of the fuel consumption meter. The fuel goes back to the fuel line going to the engine instead of returning to the fuel tanks.

The fuel consumption meter was first calibrated with diesel fuel using the actual test setup for centrifugal pumps, four-wheel tractors, two-wheel tractors, and single-cylinder small engines. For the four-wheel tractor testing the fuel consumption meter used was the Ono Sokki FX-1100 Series fuel meter, for the small engine testing it was the Ono Sokki FC-024 fuel meter that was used, and for the two-wheel tractor testing and the centrifugal pump testing the fuel meter used was the AMTEC FM-01 fuel meter. Depending on which test setup is being used, the developed fuel meter was connected parallel to existing fuel meter of that particular setup. This way, the calibration of the developed fuel meter will not interfere with the data obtained from the existing fuel meter of AMTEC. Two (2) lever valves were used to quickly change the fuel flow from one fuel meter to another. The same procedure and setup were done during the calibration and testing for gasoline fuel. The data obtained from the developed fuel meter and the existing fuel meter were compared and analyzed.

The developed fuel meter was tested on a centrifugal pump (MIZU EG-4000) that uses a diesel engine (YANMAR TF70L), a two-wheel tractor (ACT MASA powered by YANMAR TF70L diesel engine), a small engine (YANMAR L100N6), and a four-wheel tractor (YTO X704). The use of load cell sensor enables the developed fuel meter to measure bigger fuel consumption like in the four-wheel tractor testing. It was also tested for gasoline small engine (KRESS KE215R) and a gasoline centrifugal pumpset (KAWSAKI 3x3).

Analysis of Test Results

Data points that were considered as outliers were removed from the analysis. According to Aguinis *et al.* (2013) outliers are data points that deviates markedly from others. They recommend the best-practices for defining, identifying, and handling of outliers within the context of different data-analytic techniques such as regression, structural equation modeling (SEM), and multilevel modeling. By following the steps in handling outliers in a regression analysis mentioned by Aguinis *et al.* (2013), we first defined what type of outliers were present. This study had a model fit outlier, a type of influential outlier wherein the presence of data points alters the fit of a model. It can increase or decrease the model fit and oftentimes affect both the model fit and parameter estimates (e.g., slope and/or intercept coefficients). In order to identify a model fit outlier, a two-step process was introduced in the study of Aguinis et al. (2013), the first step is by identifying the data points that are most likely to have an influence on the model fit because they deviate markedly from the others in the data set. The second step is by checking whether the data points identified in step one actually has in influence on the model fit. This involves removing first the data that deviates markedly from the rest and observed the effect on the model fit (e.g., R^2). The data point that will not cause a change in the of R^2 value is retained. After checking the effect of the outliers on the model fit, the developed fuel meter was tested again to test out the adjusted calibration curve.

A paired T-test statistical analysis was used to determine the change that took effect after the implementation of the calibration equation to the Arduino code. The analysis was done for both the diesel and gasoline fuel data. In addition, the percent difference was computed for each data before and after calibration to show if there is a significant change in the result after the fuel meter was calibrated. Due to unavailability of standard to compare the computed percent difference, the researchers set their own limit of accepted percent difference which is below 10%.

Storing and recording of data

The Adafruit datalogging shield connected to the Arduino is responsible for the storing and recording of data. During testing of the fuel meter, the following data such as initial weight, final weight, time, density, fuel consumption (without calibration), fuel consumption (with calibration), and timestamp (**Figure 17**) were automatically stored and recorded in a memory card. The file was saved as .CSV file with a filename of the date it was tested. The data are retrieved by the user after testing.

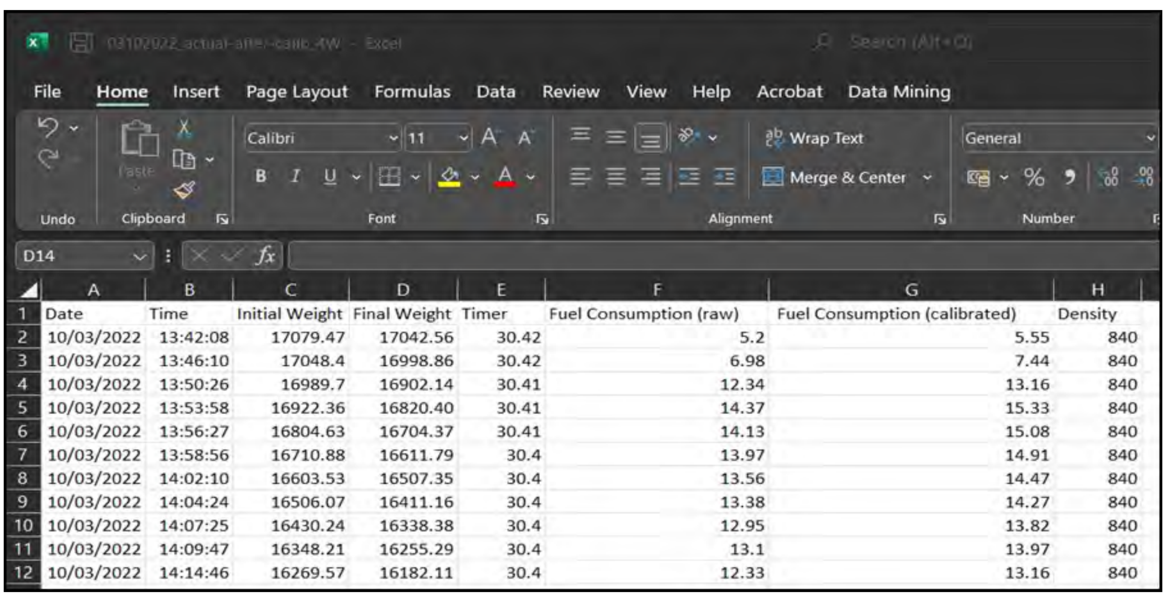
RESULTS AND DISCUSSION

Testing of Developed Fuel Consumption Meter

During the testing of the developed fuel consumption meter, it was observed that the readings from the load cell sensor is affected by the vibrations coming from the test setup causing a difficulty in reading the initial and final weight of fuel. Due to this the developed fuel meter was positioned further away from the test setup to eliminate the effect of vibrations. The equipment was initially tested for centrifugal pump testing and as previously mentioned, the centrifugal pump (MIZU EG-4000) used a diesel engine (YANMAR TF70L) and the fuel consumption during the performance testing of centrifugal pump was obtained. After the test, the two data sets were compared and the percent difference for each point was computed (**Table 1**).

Table 1. Comparison of fuel consumption using the AMTEC fuel meter and the developed fuel meter during the centrifugal pump testing (diesel engine).

No.	Fuel Consumption, L/h		Percent Difference
	AMTEC	Developed Fuel Meter	
1	1.07	0.91	16.16
2	1.27	1.06	17.63
3	1.43	1.28	11.07
4	1.54	1.57	1.96
5	1.80	1.63	9.64
6	1.89	1.63	14.77
7	1.76	1.70	3.18
8	1.83	1.69	7.68
9	1.82	1.71	5.96
10	1.83	1.76	3.90



	Date	Time	Initial Weight	Final Weight	Timer	Fuel Consumption (raw)	Fuel Consumption (calibrated)	Density
2	10/03/2022	13:42:08	17079.47	17042.56	30.42	5.2	5.55	840
3	10/03/2022	13:46:10	17048.4	16998.86	30.42	6.98	7.44	840
4	10/03/2022	13:50:26	16989.7	16902.14	30.41	12.34	13.16	840
5	10/03/2022	13:53:58	16922.36	16820.40	30.41	14.37	15.33	840
6	10/03/2022	13:56:27	16804.63	16704.37	30.41	14.13	15.08	840
7	10/03/2022	13:58:56	16710.88	16611.79	30.4	13.97	14.91	840
8	10/03/2022	14:02:10	16603.53	16507.35	30.4	13.56	14.47	840
9	10/03/2022	14:04:24	16506.07	16411.16	30.4	13.38	14.27	840
10	10/03/2022	14:07:25	16430.24	16338.38	30.4	12.95	13.82	840
11	10/03/2022	14:09:47	16348.21	16255.29	30.4	13.1	13.97	840
12	10/03/2022	14:14:46	16269.57	16182.11	30.4	12.33	13.16	840

Figure 17. A snapshot of the sample data stored and recorded.

The computed average percent difference is 9.19% which is close to the percent difference limit set by the researchers in this study. Additionally, the minimum percent difference was 1.96% and the maximum percent difference was 17.63%. These values affect the computation of the average percent difference. The average percent difference could still be lowered if the values above 10% are corrected. This will allow the researchers to properly gauge whether the data between the developed fuel meter and the existing fuel meters are significant or not.

Then, the developed fuel meter was tested on a two-wheel tractor (ACT MASA powered by YANMAR TF70L diesel engine). The average percent difference computed was 7.61% (**Table 2**). The same explanation can be said for this one since there are few points whose percent difference is much larger (19.79%) and much smaller (0.62%) than the rest which affects the computation average percent difference. Further correction to decrease the percent difference can still be made.

Table 2. Comparison of fuel consumption using the AMTEC fuel meter and the developed fuel meter during the two-wheel tractor testing (diesel engine).

No.	Fuel Consumption, L/h		Percent Difference
	AMTEC	Developed Fuel Meter	
1	0.54	0.56	2.54
2	0.58	0.64	10.31
3	0.66	0.72	8.00
4	0.77	0.79	1.67
5	0.86	1.05	19.79
6	0.95	0.96	0.62
7	1.07	1.23	13.59
8	1.26	1.24	1.85
9	1.76	1.95	10.17
Average			**7.61**

The developed fuel meter was also tested on a four-wheel tractor (YTO X704) during PTO testing. As seen in **Table 3**, the average percent difference obtained during the four-wheel testing was 10.66%. Although there is no available standard for comparison, the 10% limit set by the researchers were followed as the accepted value. In addition, the maximum percent difference obtained was 27.12% and the minimum is 2.33%. Data that deviates further from the AMTEC fuel meter data will have an effect on the accuracy of the developed fuel meter and needs further correction.

Table 3. Comparison of fuel consumption using the AMTEC fuel meter and the developed fuel meter during the four-wheel tractor testing (diesel engine).

No.	Fuel Consumption, L/h		Percent Difference
	AMTEC	Developed Fuel Meter	
1	6.66	7.76	15.27
2	10.55	13.86	27.12
3	14.32	15.30	6.62
4	18.85	16.64	12.43
5	18.89	19.33	2.33
6	19.37	17.45	10.43
7	19.55	18.11	7.67
8	20.82	18.53	11.62
9	21.46	19.78	8.15
10	21.54	19.98	7.51
11	21.79	19.53	10.92
12	22.20	20.29	8.99
13	22.64	20.58	9.53
Average			**10.66**

Lastly, the fuel meter was tested on a single-cylinder small engine (YANMAR L100N6). The fuel consumption during the varying load test was recorded and compared. The average percent difference calculated was 4.10% (**Table 4**). Although the percent difference for each point are low in reference to the 10% limit, it can still be decreased through corrections.

After testing the developed fuel meter to four different tests the computed average percent difference were 9.19%, 7.61%, 10.66%, and 4.10%.

Table 4. Comparison of fuel consumption using the AMTEC fuel meter and the developed fuel meter during the four-wheel tractor testing (diesel engine).

No.	Fuel Consumption, L/h		Percent Difference
	AMTEC	Developed Fuel Meter	
1	1.22	1.18	3.33
2	1.51	1.49	1.33
3	1.61	1.56	3.15
4	1.74	1.63	6.53
5	1.84	1.74	5.59
6	1.82	1.77	2.79
7	1.81	1.77	2.23
8	1.89	1.78	5.99
9	1.91	1.87	2.12
11	2.10	1.97	6.39
12	2.13	2.06	3.34
13	2.16	2.12	1.87
14	2.40	2.30	4.26
15	2.61	2.42	7.55
Average			**4.10**

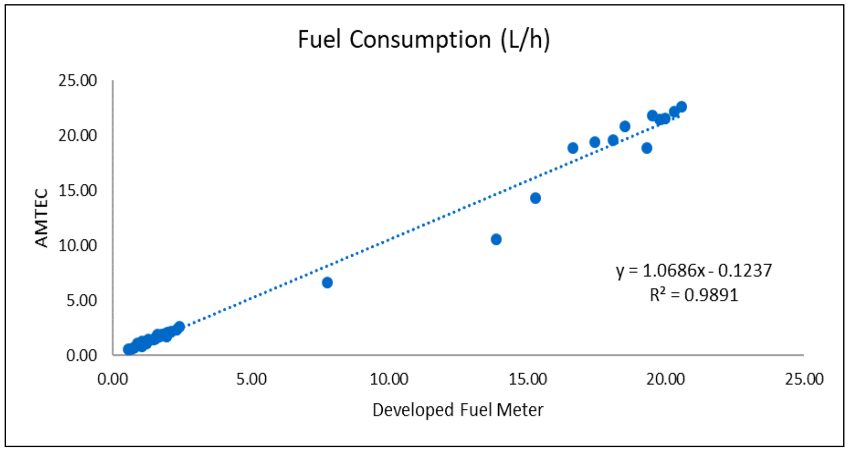


Figure 18. Calibration curve of the fuel consumption obtained from the developed fuel meter vs AMTEC fuel meter (Diesel).

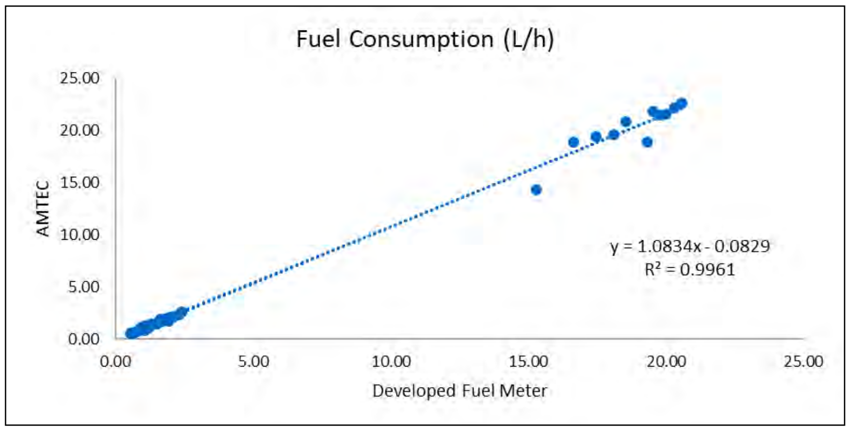


Figure 19. Adjusted calibration curve of the fuel consumption obtained from the developed fuel meter vs AMTEC fuel meter (Diesel).

These average values may seem like good values already considering the 10% limit, however, it can still be lowered to get a more accurate results. Hence, calibration was performed on the fuel meter simply by comparing the two datasets and linear regression was applied to generate a calibration equation as shown in **Figure 18.**

Removing the outliers one by one – data points 1, and 2 in **Table 3** – the R^2 changes in an increasing manner and another calibration curve was generated as shown in **Figure 19**. The new equation was implemented in the Arduino code and another run of testing was conducted.

After the adjusted calibration curve was obtained, the fuel meter was again tested on the four-wheel tractor testing and small engine testing. The average percent difference for the four-wheel tractor decreased from 10.66% to 1.49% after calibration. The fuel meter was tested again on small engine. The average percent difference decreased from 4.10% to 3.85% after applying the calibration equation. By further decreasing the percent difference between the two datasets, it also increases the accuracy of the developed fuel meter. **Table 5** and **Table 6** show the obtained data from the four-wheel tractor testing and small engine testing, respectively.

The developed fuel meter was also tested on gasoline small engine (KRESS KE215R) and centrifugal pump (KAWASAKI 3x3 pumpset). As seen in **Table 7,** the computed percent differences were all above 10% which is beyond the set limit. In order to improve these values further correction through calibration is needed.

Table 5. Comparison of fuel consumption using the AMTEC fuel meter and the developed fuel meter after calibration during the four-wheel tractor testing (diesel engine).

No.	Fuel Consumption, L/h		Percent Difference
	AMTEC[1]	Developed Fuel Meter	
1	5.85	5.68	2.95
2	7.78	7.73	0.64
3	13.00	13.39	2.96
4	15.21	15.41	1.31
5	15.36	15.23	0.85
6	15.17	15.03	0.93
7	14.72	14.59	0.89
8	14.34	14.26	0.56
9	13.77	13.90	0.94
10	13.66	13.91	1.81
11	13.73	13.38	2.58
Average			**1.49**

[1]*Ono Sokki FX-1100 Series*

Table 6. Comparison of fuel consumption using the AMTEC fuel meter and the developed fuel meter after calibration during the small engine testing (diesel engine).

No.	Fuel Consumption, L/h		Percent Difference
	AMTEC[1]	Developed Fuel Meter	
1	2.13	2.06	3.34
2	2.12	2.23	5.06
3	2.10	1.97	6.39
4	2.02	1.92	5.08
5	1.89	1.93	2.09
6	1.89	1.78	5.99
7	1.84	1.74	5.59
8	1.76	1.74	1.14
9	1.72	1.72	0
Average			**3.85**

[1]*Ono Sokki FC-024*

Meanwhile, the fuel consumption obtained during the varying load test of a gasoline small engine is shown in **Table 8**. Similar to **Table 7,** the computed percent differences were all above 10% which is beyond the set limit as well. These values greatly affects the accuracy of the developed fuel meter. The lower the percent difference the better effect it has on the accuracy of the fuel meter. In order to achieve a lower percent difference, further corrections were applied by comparing the two datasets and linear regression was applied. A calibration equation was generated as shown in **Figure 20.**

The generated equation for gasoline was implemented on the Arduino code and the fuel meter

Table 7. Comparison of fuel consumption using the AMTEC fuel meter and the developed fuel meter during the centrifugal pump testing (gasoline).

No.	Fuel Consumption, L/h		Percent Difference
	AMTEC[1]	Developed Fuel Meter	
1	1.51	1.84	19.96
2	1.57	1.82	14.94
3	1.58	1.91	18.95
4	1.60	1.85	14.48
5	1.67	1.94	14.70
6	1.69	1.91	12.50
7	1.75	2.12	18.92
8	1.80	2.18	19.00
9	1.81	2.06	13.07
10	1.81	2.19	19.00
11	1.83	2.10	13.78
12	1.93	2.18	11.99
13	1.94	2.16	10.91
14	1.95	2.36	19.12
15	1.96	2.17	10.18
16	2.03	2.33	13.91
17	2.04	2.35	14.08
Average			**15.26**

[1]*AMTEC FM-01*

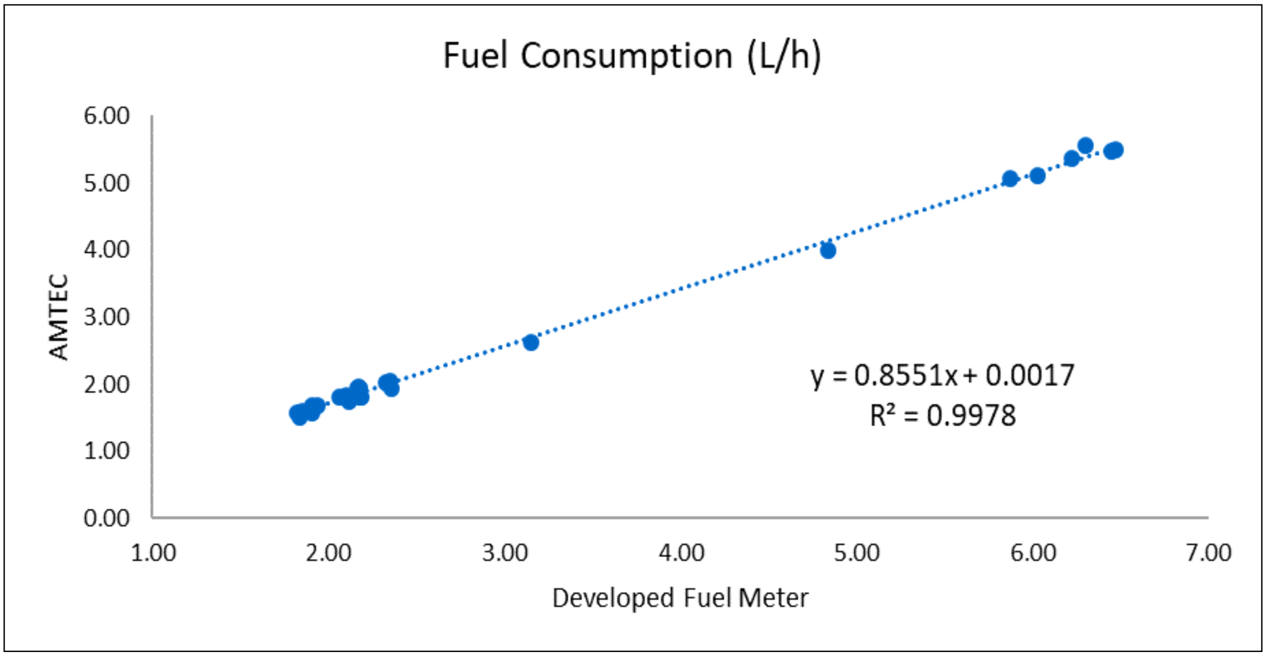


Figure 20. Calibration curve of the fuel consumption obtained from the developed fuel meter vs AMTEC fuel meter (Gasoline).

was tested again on the centrifugal pump testing. As seen in **Table 9**, the average percent difference decreased from 15.26% to 5.81% after applying the calibration equation to the Arduino code.

Table 8. Comparison of fuel consumption using the AMTEC fuel meter and the developed fuel meter during the small engine testing (gasoline).

No.	Fuel Consumption, L/h		Percent Difference
	AMTEC[1]	Developed Fuel Meter	
1	2.63	3.15	18.01
2	3.99	4.84	19.33
3	5.06	5.87	14.76
4	5.10	6.03	16.73
5	5.37	6.22	14.61
6	5.46	6.45	16.57
7	5.50	6.47	16.28
8	5.56	6.30	12.40
Average			**16.09**

[1]Ono Sokki FC-024

Table 9. Comparison of fuel consumption using the AMTEC fuel meter and the developed fuel meter after calibration during the centrifugal pump testing (gasoline).

No.	Fuel Consumption, L/h		Percent Difference
	AMTEC[1]	Developed Fuel Meter	
1	1.26	1.30	3.07
2	1.43	1.52	6.40
3	1.51	1.64	8.38
4	1.59	1.55	2.25
5	1.61	1.58	2.03
6	1.62	1.78	9.40
7	1.69	1.57	7.87
8	1.64	1.54	6.46
9	1.35	1.46	7.61
10	1.61	1.54	4.67
Average			**5.81**

[1]AMTEC FM-01

Statistical Analysis

The result of the Paired T-test for the diesel fuel data before and after calibration is shown in **Table 10.** It showed that before calibration at a 5% level of significance the difference between the averages of the two datasets has no significant variation since p=0.054 is greater than 0.05. Results after the calibration of the developed fuel meter showed that at a 5% level of significance, there is also no significant variation (p=0.550) between the two datasets. This means the values obtained from the developed fuel meter are acceptable.

Table 11. Paired T-test analysis for Gasoline fuel before and after calibration.

	Before Calibration		After Calibration	
	AMTEC[1]	Developed Fuel Meter	AMTEC[1]	Developed Fuel Meter
Mean	2.76	3.23	1.53	1.55
Variance	2.420	3.310	0.020	0.015
Observations	25	25	10	10
Pearson Correlation	0.999		0.708	
Hypothesized Mean Difference	0		0	
df	24		9	
t Stat	-8.510		-0.528	
P(T<=t) one-tail	$5.17E^{-09}$		0.305	
t Critical one-tail	1.71		1.83	
P(T<=t) two-tail	$1.03E^{-08}$		0.610	
t Critical two-tail	2.06		2.26	

[1]AMTEC FM-01.

For the gasoline fuel data, the same statistical analysis was applied before and after calibration. **Table 11** shows the result of the Paired T-test analysis before and after calibration. Before calibration, at a 5% level of significance the difference between the averages of the two datasets is big enough to have significant variation since $p=1.03e^{-8}$ is less than 0.05. Such a result is also supported by the computed percent difference shown in the previous table. This means that the values from the developed fuel meter needs further correction to be considered acceptable. After calibration, the result showed that at a 5% level of significance the difference between the averages of the two datasets is no longer statistically significant (p=0.610) after the calibration equation was applied to the Arduino code. After the huge drop in percent difference (**Table 9**) and the two datasets being not statistically significant after calibration indicates that the developed fuel meter can be considered as good as the existing fuel meters.

Table 10. Paired T-test analysis for Diesel fuel before and after calibration.

	Before Calibration		After Calibration	
	AMTEC[1]	Developed Fuel Meter	AMTEC[1]	Developed Fuel Meter
Mean	6.21	5.93	8.00	7.98
Variance	64.03	55.47	36.91	37.24
Observations	47	47	20	20
Pearson Correlation	0.994		8.000	7.980
Hypothesized Mean Difference	0		0	
df	46		19	
t Stat	1.980		0.609	
P(T<=t) one-tail	0.027		0.275	
t Critical one-tail	1.68		1.73	
P(T<=t) two-tail	0.054		0.550	
t Critical two-tail	2.01		2.09	

[1]The fuel meters used were Ono Sokki FX-1100 Series, Ono Sokki FC-024, and AMTEC FM-01.

Cost comparison

Table 12 shows the comparison between the cost of buying commercially-available fuel meter versus developing your own fuel meter using readily-available and locally-sourced materials (with overall cost of design and fabrication not exceeding PhP 500,000).

Table 12. Comparison of cost between the developed fuel meter and the commercially available fuel meter.

Description	Unit Cost (PhP)	
Commercially available fuel meter (Ono Sokki FM-3100)	**1,348,000.00**[1]	
Developed fuel meter	**25,125.77**[2]	
a. *Fabrication*		
Chemical hose		*2,050.00*
Angle bar (1.5x1.5)		*1,410.00*
GI sheet		*1,080.00*
Angle bar (1.0x1.0)		*640.00*
Gate valve		*403.00*
GI nipple		*400.00*
Welding rod		*350.00*
Paint primer, thinner and paint brush		*350.00*
GI elbow		*220.00*
b. *Fuel Meter Controller*		
Solenoid valve		*2,069.72*
AC/DC adapter, 24V		*1,372.16*
Datalogging shield		*1,205.88*
Load cell		*729.00*
Arduino UNO		*500.00*
Black box		*310.00*
20x4 LCD display		*250.00*
Wire connectors		*200.00*
Arduino pin headers (female)		*150.00*
2-channel Relay Module		*120.00*
Double-sided PCB		*100.00*
HX711 load cell amplifier module		*49.00*
c. *Labor Cost (assuming 80% of material cost)*		*11,167.01*

Around PHP1.3M were saved by AMTEC in the development of a fuel consumption meter.

CONCLUSION

A simplified fuel meter was developed with the use of the gravimetric principle. An Arduino microcontroller and the components for the data acquisition were used in the other components. The developed fuel meter can be used for both diesel and gasoline fuel, but separate tanks were used. It was observed during testing that the developed fuel meter was affected by vibrations coming from the test setup causing difficulty in obtaining proper measurement. The developed fuel meter was calibrated by comparing the data to the data obtained using the existing fuel meter of AMTEC and the percent difference were calculated before and after calibration. The percent difference obtained before calibration ranges from 1.05% to 27.12% and after calibration ranges from 0% to 6.39% for diesel fuel in comparison to the existing fuel meter (Ono Sokki FX-1100 Series). The percent difference obtained before calibration ranges from 10.18% to 19.96% and 2.03% to 9.40% after calibration for gasoline fuel in comparison to the volumetric method fuel meter of AMTEC. The paired T-test analysis at a 5% level of significance showed no significant variation for diesel fuel before calibration ($p=0.054$) and after calibration ($p=0.550$). At a 5% level of significance, significant variation was observed for gasoline fuel before calibration ($p=1.03e^{-8}$) but no significant variation showed after calibration ($p=0.610$).

In conclusion, we were able to design and develop a fuel meter with data logging capability that is cheaper compared to the commercially-available fuel meter. Even after the problem with vibrations, the result still showed no significant variation with the existing fuel meters. Therefore, the developed fuel meter can be considered as good as the existing fuel meters of AMTEC.

RECOMMENDATIONS

The researchers recommend modifying or improving the container that houses the electrical components to protect it from electronic interfaces. In addition, a voltage regulator for the power supply is recommended to properly ensure that the system is getting the right amount of voltage each time. Moreover, it was observed during testing that the measurement of fuel weight was highly affected by vibration making it difficult to obtain proper measurement. It is recommended to use dampers to eliminate the effect of vibration. Alternatively, use a different sensor that is not affected by vibrations such as an inline flow sensor. An inline flow sensor is not affected by vibration and will allow the user to get the fuel consumption reading without following the gravimetric approach. There is no need to obtain the initial and final weight after a specific time since the measurement is done real-time. This will also make the algorithm code less complicated, the design of the fuel meter simpler, and the fuel meter easier to transport during field testing of agricultural machinery. However, the wide range capacity of the inline flow sensor must be selected to be more flexible and appropriate for testing of machinery.

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