Arduino-Based Battery Monitoring System with State of Charge and Remaining Useful Time Estimation

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***Abstract*— This paper presents a battery management system for lead-acid battery bank used in e-vehicle. It is incorporated with a diagnostic, measurement and monitoring system for the improvement of lead acid battery performance as far as its efficiency, capacity and conservation is concerned. This matter calls the need of research on traction batteries as an insatiate demand exists for smaller vehicles with lightweight and portable equipment. It is of great importance that batteries are accurately assessed or diagnosed before having it rented or swapped for the quality to be maintained. The measurement of the battery's State-of-Charge and State-of-Health is derived from its load voltage, no-load voltage, load current and temperature during experimentation. The estimation of State-of-Charge, State-of-Health, Discharge Rate, and Remaining Useful Life are then derived by utilizing the concept of correlation and regression from the yielded real-time parameters recorded to the SD card module. Furthermore, the results of the management system show that the device operates real-time and accurate regarding predictions on Remaining Useful Life and Distance to be travelled. It also provides recommendations or solutions for any abnormal state the battery encounters. This study paves the way for thorough and continuous development of lead acid battery identification, diagnosis and monitoring that is a profound advancement in the E-Vehicle industry.**

***Keywords*— Battery Management System, Lead-acid, Arduino-based management system, Electric Vehicle, State-of-Charge, State-of-Health, Remaining Useful Time, Discharge Rate**

I. INTRODUCTION

Utilization of public transportation is an aspect of economic advancement that the government continues to improve. With the emerging technology of transportation in the Philippines, e-vehicle became a trend last 2015 inviting manufacturers for production [1]. With the growing industry of e-vehicle, the traction battery industry, as an essential part of its structure, will also be prominent.

The battery in an electric vehicle system is the counterpart of fuel tank on conventional vehicle; traction battery replaces gasoline. The type of traction battery commonly used in the Philippines is lead acid battery based on the statistics analyzed by the Electric Vehicle Association of the Philippines (eVap), the production of e-vehicles that uses lead-acid batteries are greater than those vehicles that uses lithium batteries . It is economical for it is inexpensive compared to others [2]. In addition, it is simple to manufacture as its structure of lead plates and electrolyte are made of diluted sulfuric acid [3].

Electromechanical batteries are design from electrical analogy by means of having notorious network of electrical components like electromotive forces, resistors, and capacitors. The structure of the cell is modeled by two approaches are modeling each part as electrical element or modeling the cell behavior as black box. Black box approach is the interpretation of the output of the terminals [4]. Battery modeling can be acquired from artificial intelligence where fuzzy logic is used to present discharging of lead acid batteries. The discharging data are acquired by the manipulation of relationships between the open-circuit terminal voltage of the battery, the output currents, and the state of charge [5].

Battery identification, diagnosis and monitoring is a technology that is not yet available among e-trike owners and e-trike battery shops in the Philippines. It is of great importance that batteries are accurately assessed or diagnosed before having it rented or swapped for the quality be maintained and not be compromised. However, e-trike owners and e-trike battery shops are only capable of visual inspection for any physical defects like wears and tears, and by means of a voltmeter for assessing the health of the battery, wherein State-of-Charge (SOC) is confused with State-of-Health (SOH). Both techniques do not exhibit reliable estimation and decision-making is at risk.

As a solution, the researchers of the study proposed as system that would have a deep understanding about the parameters to consider upon diagnosing an e-trike battery like the lead acid battery. The researchers specifically aims to: (1) design and develop an electronic circuit for the Arduino-based data acquisition system for the battery's no-load voltage, load voltage, current, and temperature, and (2) develop an Arduino-based identification and diagnostic system that stores and validates battery performance through information storage for the initialization, reading, and writing of the battery's performance history used for battery.

The success of the study will be a source of the e-trike battery shops for better battery diagnosis and business judgement. Over and above that, it will pave the way for thorough and continuous development of lead acid battery identification, diagnosis and monitoring that is a profound advancement in the e-vehicle industry.

This research paper is organized as follows: Section 2 pertains to the gaps and limitations of the related researches, Section 3 defines the materials and methods used by the researchers, Section 4 explains the detection and database results of the study, Section 5 declares the conclusion and Section 6 enumerates possible future works of the research.

II. Related Works

Recognizable battery degradation assessments have been emerged even before the creation of electric vehicle. Various methods and variables were introduced for estimation of measurements of battery's SOC and SOH.

In [4], researchers introduces a method that adopts known cell-balancing circuits for individual estimation of cell's voltage and current from a battery bank or battery string terminal. The methods include control strategies and algorithms by manipulating balancing circuits to observe battery subsystems. It is concluded that large balancing current circuit is ideal for accurate measurement.

Diao *et al,* use internal resistance mainly to evaluate the health status (SOH) of battery cells and packs to identify the end - of- life batteries. However, this method may lead to a different conclusion of the battery SOH due to the capacity independence from the internal resistance. A ratio between the current maximum energy available (MAA) and the rated total energy is proposed and defined by the energy SOH for a battery pack. The SOH is more accurate to reflect the current battery pack status compared to capacity and power SOH, which includes both degradation and inconsistency of capacity and domestic resistance. The superiority of this method is demonstrated by analyzing data and comparing different methods. [5]

In [6], researchers utilized probability distribution adopted the concept of Monotonic echo sate Networks or MONESNs algorithm for tracking nonlinear degradation patterns of battery-RUL estimation. A correlation model between health index and battery capacity is developed. Two sets of data of lithium-ion battery are used to prove the efficiency of the proposed method.

Liu *et al* proposes calculation and monitoring of the SOC, health status (SOH) and functionality (SOF) of the electric vehicle BMS. The present maximum ability to reduce the error of the SOC estimate will therefore be redefined. The SOC measurements show that 0.334 percent is the maximum error. In addition, the article proposes that SOF based on SOC and SOH reveal the system's driving power. [7]

In [8], a snapshot-based model is constructed by the use of recurrent neural network (RNN) that is suitable in handling sequential data with the data of the ratio of current and voltage during the charge cycle. The used of long-short term memory neural network as the improved variant of the standard recurrent neural network. The neural network of former data the performance of a battery is used to adopt the snapshot-based approach and is necessary to minimize the noise effect.

III. Methodology

In this research, the battery management system was deployed in a battery rental shop for public transportation.

Fig. 1 shows the block diagrams of the entire system. Batteries, with and without the proposed device for identification and measurement, are subjected to be manually selected by the owner of the battery shop. The specification of new batteries (without the device) are stored in database then, from the user interface a new SD card will undergo decoding for the battery specifications. The SD card module served as the identifier of the battery that also records data every charging and discharging. The measuring system is an Arduino-based voltmeter, ohmmeter, ammeter and thermometer circuit used for the diagnosis and estimation of battery life. In diagnostic system, the data from the SD card module, battery specifications and the measured parameters were all transferred to the database. The calculation and prediction of remaining life of the battery in time was done by a mathematical model with the help of the measured value and the history of the battery. The monitoring system includes display of measured parameters, the produced critical parameters and the estimation of the battery life by means of time. The data gathered from the lead acid battery over time was also available in display to show the performance of the battery in every charged/discharged cycle. The degradation speed, along with the graphical representation of the battery performance, is also available.

A. Research Locale

The proponents were subjected to locate shops in Bacoor, Cavite, Philippines that offer rental and/or swapping of lead acid batteries. For that location, the output of the study was used for battery bank testing and diagnosis. The acquired data and data evaluation would be presented to the shop owners.

B. Hardware Development

The hardware development consists of measuring and identification technology. The measurement section, an Arduino-based measuring circuit will be an equipment to determine the real-time parameters of the battery. The first level diagnosis will also undergo to the Arduino-based voltmeter, ohmmeter, ammeter and thermometer circuits that will be stored to the integrated microSD card module. The integration of the microSD card module functions also as the unique identification for the system. It will be given a serial number for a set of battery bank.

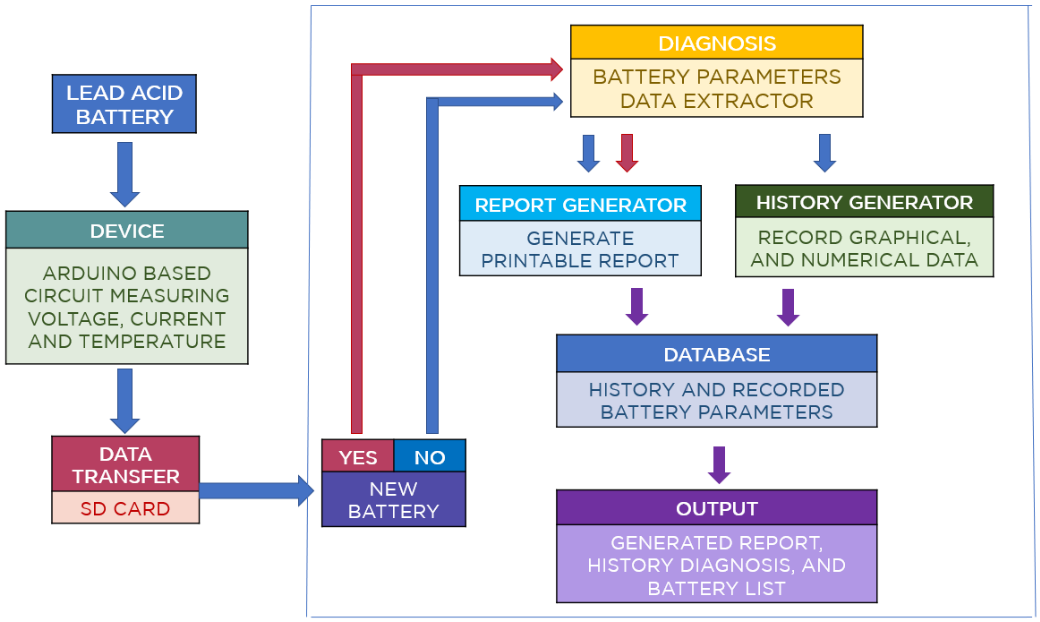

Figure 1 System Block Diagram

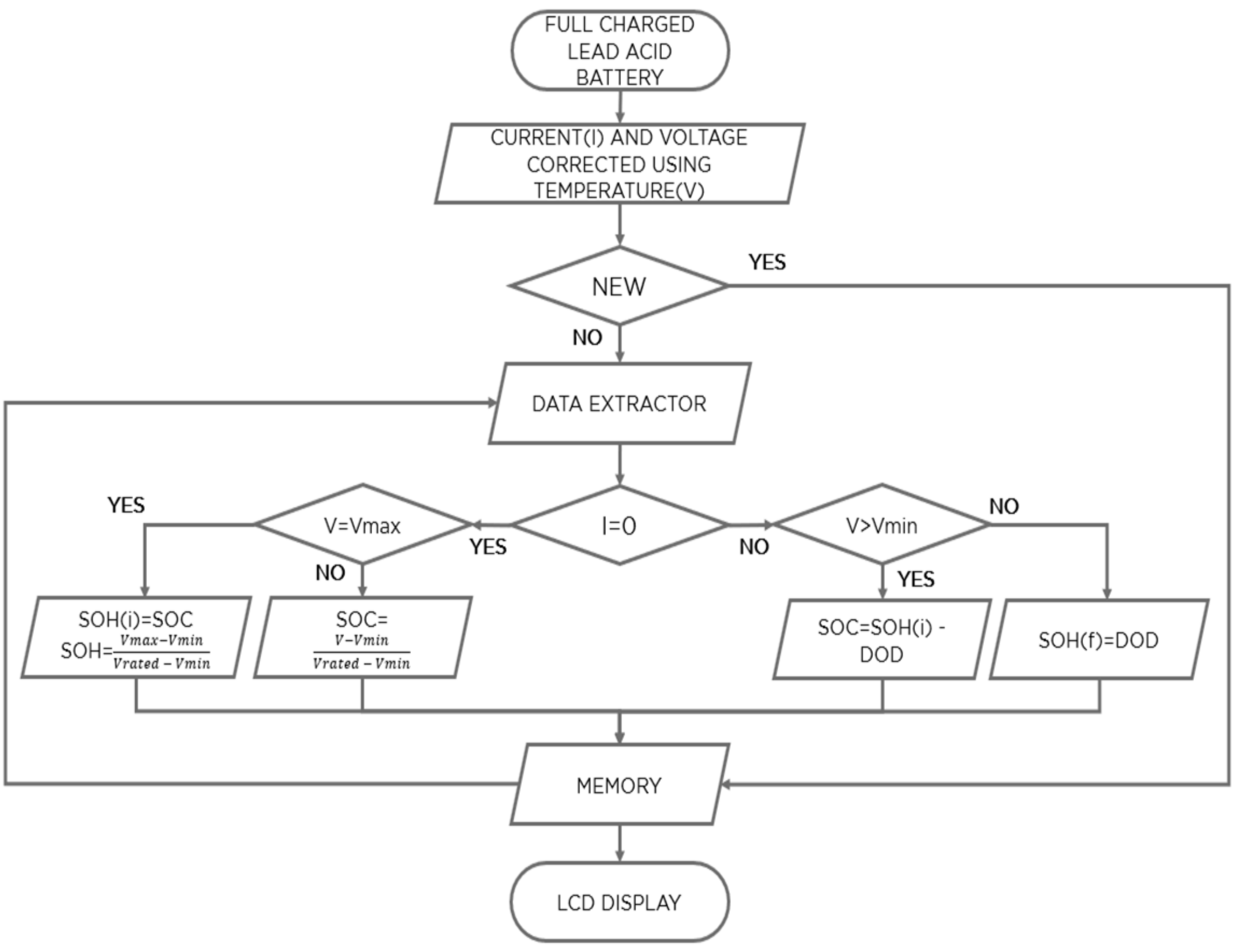

Figure 2 Measurement of SOC and SOH Flow Chart

C. Software Development

The software development of the proposed system used the application of Arduino IDE for programming the microcontroller of the system, MySQL for data base and Python for the system user interface.

The microcontroller is programmed to acquire real-time parameters with computational analysis in obtaining the battery's internal resistance, SoC, SoH, Discharge Rate, and Depth-of-discharge (DOD). Fig.2 shows the data transfer on the device alone of SOC and SOH Measurement. With the process flow presented measured real-time variables are also programmed to be shown on the LCD.

D. Computational Analysis

In this research, the reserachers categorized the health of the battery as SOC and SOH. SOC is the ratio of the remaining charge of the battery to its full charged state. In other words SOC is the percentage of the remaining charged of the battery to the maximum charge of the battery. For calculating the SoC the formula in eq 11 from [37] is used.

$$\mathbf{SOC = (Q_R / Q_M) \times 100\%} \qquad (1)$$

$$\mathbf{SOC = SOC_o - (\frac{1}{Cn}\int_{t1}^{t2} Idt) \times 100\%,} \qquad (2)$$

For new full charged batteries the initial state of charge (SOC_o) can be obtained easily, since the new battery at full charged will meet its maximum capacity. The SOC_o for full charged new battery is equal to 100% because $Q_R = Q_M$ and as stated in Equation 1.

$$\mathbf{SOC_o = (Q_M / Q_M) \times 100\%} \qquad (3)$$

$$\mathbf{SOC_o = 100\%} \qquad (4)$$

SOC can be calculated using another parameter, such as cell voltage (V_{CELL}) and the original voltage of the battery before it gets internal resistance (V_O), due to the directly proporttional relationship of charge and voltage.

$$\mathbf{SOC_V = \frac{V(cell)}{Vo}\, x\ 100\%} \qquad (5)$$

$$\mathbf{V_{CELL} = V_{BAT} - V_{INTERNAL\ RESISTANCE}} \qquad (6)$$

Voltage of the battery will increased by a certain value (**α,** normally 0.003V) for each cell if the temperature of the battery is below the ambient temperature and vice versa; Where n is equal to the number of cell/cells.

$$\mathbf{SOC_V = \frac{V(measured) \pm n(\alpha)}{Vo}\, x\ 100\%} \qquad (7)$$

Using Equation 2 and Equation 5, where $SOC_V = SOC_o$,new equation is derrived

$$\mathbf{SOC = (\frac{V(measured) \pm n(\alpha)}{Vo} - \frac{1}{Cn}\int_{t1}^{t2} Idt) x\ 100\%} \qquad (8)$$

The new battery is full charged the initial discharge ($Q_{INITILA\ DISCHARGE}$) is equal to 0 so that

$$\boldsymbol{Q(discharge) = \int_{t1}^{t2} Idt} \qquad (9)$$

Substituting Equation 9 to Equation 8, where C_n is the original capacity Q_O of the battery will lead to

$$\mathbf{SOC = (\frac{V(measured) \pm n(\alpha)}{Vo} - \frac{Q(discharge)}{Q(o)}) x\ 100\%} \qquad (10)$$

The researchers calculated the remaining time of the battery in terms of hours and minutes. Where t(average) is equal to the average operation time of the battery (normally 6 hrs).

$$\mathbf{t(remaining) = t(average)\ x\ SOC} \qquad (11)$$

Another parameter to be measured in order to know the health of the battery is the SOH. There are many ways to interpret the SOH such as internal resistance, voltage and charge.

$$\mathbf{SOH_R = [1 - \frac{R(eol) - R(internal\ resistance)}{R(eol) - R(o)}]\, x\ 100\%} \qquad (12)$$

Where $\mathbf{SOH_R}$ is the internal resistant state of health of the battery, R_{EOL} is the resistance of the battery to reach its end of life, and R_O is the rated internal resistance of the battery.

$$\mathbf{SOH_R = (\frac{V(noload) - V(load)}{R(eol)xI(measured)})\, x\ 100\%} \qquad (13)$$

Degradation of the battery is equal to the decrease of the SOH over a period of time

$$\text{Degradation} = 1 - \text{SOH} \qquad (14)$$

E. Device setup

This section presents the different views of the developed device for the proposed battery management system by the proponents. Dimensions are measured in terms of inches (in). The following figures shows the integration of the material into a compact device.

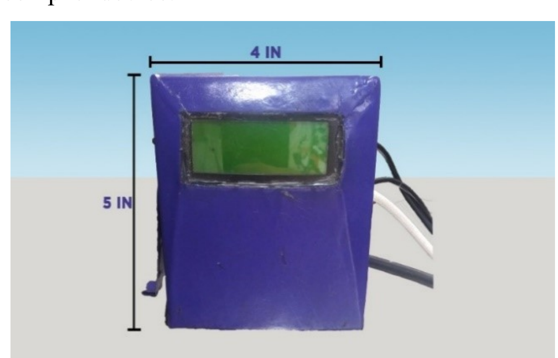

Figure 2 BattMan Front View

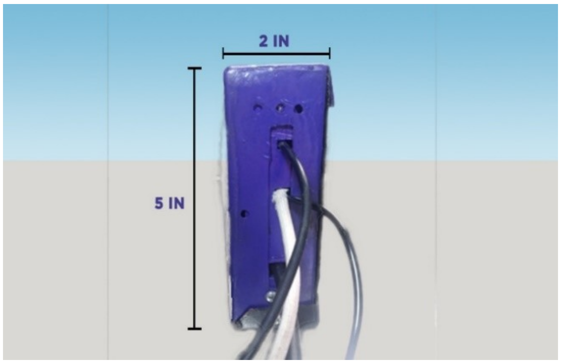

Figure 3 BattMan Right Side View

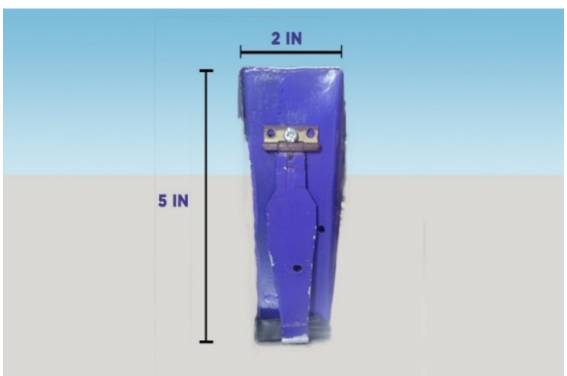

Figure 4 BattMan Left Side View

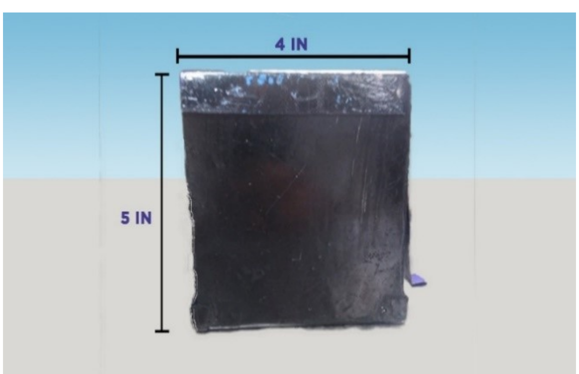

Figure 5 BattMan Back View

IV. Results and Discussions

A. Data and Results

TABLE I.
FIRST TESTING: State-of-Health and Depth of Discharge

Battery		BATTMAN-N1	BATTMAN-N2	BATTMAN-N3
Decreased in SOH (%)	1st Cycle	0.09	0.09	0.09
	5th Cycle	0.09	0.08	0.09
	10th Cycle	0.08	0.09	0.09
Average DOD (%)		91.93	61.46	31.78
Average Current (A)		1.29	1.33	1.26

TABLE II.
SECOND TESTING: State-of-Health and Depth of Discharge

Battery		BATTMAN-3M1	BATTMAN-3M2
Decreased in SOH (%)	Report-1	0.14	0.18
	Report-2	0.14	0.16
	Report-3	0.13	0.17
	Report-4	0.13	0.18
	Report-5	0.13	0.17
Average DOD (%)		60.46	91.18

TABLE III.
THIRD TESTING: State-of-Health and Depth of Discharge

Battery		BATTMAN-3M1	BATTMAN-3M2
Decreased in SOH (%)	Report-1	0.15	0.17
	Report-2	0.14	0.17
	Report-3	0.14	0.18
	Report-4	0.14	0.16
	Report-5	0.13	0.13
Average DOD (%)		61.07	90.40
Average Current (A)		13.42	13.40

TABLE I and TABLE III are the two experiments between batteries using varied current. TABLE I is the measurements with low current and TABLE II is the measurements with high currents. The expected DOD upon experimentation was 90%, 60% and 30%. However, strict monitoring on the batteries became a challenge which is why the actual DOD gathered was slightly different than the expected. It is greatly observed that the Decrease in SoH is very little among the three batteries due to small difference in current. Also, the big difference in the DOD among the three batteries didn't really affect the Decrease in SOH.

The TABLE IV. is the new sets of data like Days Used and Predicted Remaining Service Life. Used Days is the number of days passed from the purchase date. Predicted EOL is defined as the number of days till the battery wears out. The prediction is based of the current remaining SOH which is determined thru the battery's load load voltage, no-load voltage, mean current, maximum current, maximum temperature and DOD. From the five (5) sample batteries, five sets of data gathering/report were taken out based on different age.

TABLE IV.
DATA REPORT: Predicted EOL of Different Tested Batteries

Battery	Report Number	Report Date	Days Used	Predicted EOL
BATTMAN-N2	48	23-Jun-20	7	169
	54	24-Jun-20	8	167

	60	27-Jun-20	11	162
	66	29-Jun-20	13	160
	72	2-Jul-20	16	155
BATTMAN-1M	46	22-Jun-20	30	147
	58	26-Jun-20	34	141
	67	29-Jun-20	37	136
	74	3-Jul-20	41	130
	77	5-Jul-20	45	127
BATTMAN-2M	49	23-Jun-20	60	117
	61	27-Jun-20	64	111
	70	30-Jun-20	67	106
	75	3-Jul-20	71	101
	78	5-Jul-20	73	98
BATTMAN-3M2	45	22-Jun-20	90	78
	51	25-Jun-20	93	73
	57	26-Jun-20	94	70
	63	28-Jun-20	96	67
	69	30-Jun-20	98	64
BATTMAN-4M	52	25-Jun-20	120	57
	64	28-Jun-20	123	52
	73	2-Jul-20	127	45
	76	3-Jul-20	128	43
	79	5-Jul-20	130	39

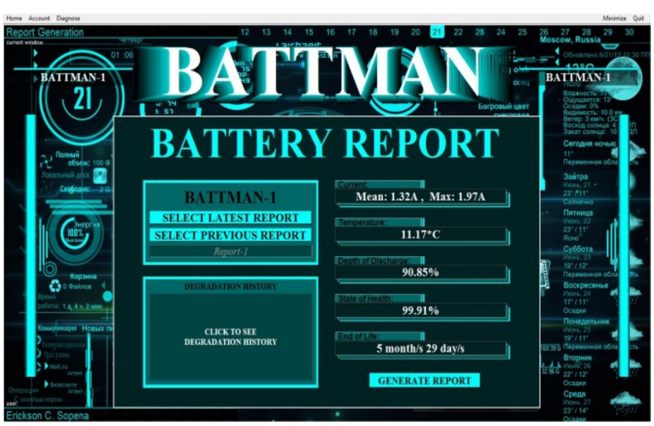

Figure 6 System User Interface

B. *Data of Report*

In addition to the indicator of installed on the device with the data acquisition specification of the device the researchers developed user interface to extract and interpret data from the SD card installed in the device. Stated technologies: MySQL and Python were used for the interface development. The interface is programmed to diagnose the data for prediction of EOL as presented on TABLE IV. Figure 6 is a preview of summarized evaluation of a battery named as BATTMAN-1.

V. CONCLUSION

Based on the summary of findings, the proponents came up to the following conclusions: (1) In determining the battery's End-of-Life, parameters like no-load voltage, load voltage, mean current, maximum current, maximum temperature, DOD and Charge- Discharge cycle should be carefully measured. Large battery consumption or DOD will occur if the discharge current was low. It showed in the data that DOD doesn't affect the battery life since the discharged current was low. However, based on the data, with low discharge current and low DOD, the battery's SOH continues to decrease due to its charge-discharge cycle, (2) SOH will still decrease no matter how efficient the battery was used. If the battery was discharged with high current, the decrease in SOH is great and evident. The data showed that battery ageing doesn't affect the decrease in SOH. Basically, the battery got consumed easily as the SOH decreases continuously. In addition, the increase in charge-discharge cycle of the battery contributed to the decrease in SOH, (3) the temperature, when high, affects battery consumption and may also cause serious damage like overheating. High discharge current was found to consume the battery easily, (4) it was confirmed that battery life was prolonged when the e-trike keeps constant speed than speeding up then stop and vice versa. It was observed that e-trike with varying speed consumes high current which greatly degrades the battery life. Also, overloading an e-trike experiences the same. The battery life was also prolonged when the difference between the ambient (external) and internal temperature was kept at 10 degrees Celsius. Not completely exhausting the battery and recharging it when 20% charge remains added to prolonging the battery life.

VI. FUTURE WORK

For further research related to this study, here are some of the recommendations from the proponents: (1) Estimation of Remaining Useful Distance. The study only developed BattMan capable of predicting the Remaining Useful Life in terms of Time and not what's left to travel, (2) More sample data acquisition per seconds. The group had a hard time gathering data because of the pandemic, (3) testing of different battery capacities. Manufacturers have produced e-trikes of higher battery capacity for larger accommodation, (4) Real-time data acquisition to database using IoT. This study requires human force to ensure the security of data from the SD Card till it makes to the database on the shop owner's personal computer, and (5) Coordinate tracker for e-trike.

ACKNOWLEDGMENT

The researchers would like to express their deepest gratitude to Wilmer Mirandilla, Mr. Bean E-bike Shop owner of Camella Bacoor Cavite for allowing the proponents to use their vehicles for the deployment of the project.

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