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M.S. Thesis

2019

BATTERY TEST AND MANAGEMENT SYSTEM

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IŞIK UNIVERSITY
2019

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B.S., Electrical & Electronic Engineering, IŞIK UNIVERSITY, 2016
Submitted to the Graduate School of Science and Engineering
in partial fulfillment of the requirements for the degree of
Master of Science
in
Electronics Engineering

IŞIK UNIVERSITY
2019

IŞIK UNIVERSITY
GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

BATTERY TEST AND MANAGEMENT SYSTEM

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APPROVAL DATE: 28 / 05 / 2019

Battery Test and Management System

Abstract

This thesis is about meeting and answering the needs of devices with batteries for battery testing and management.

The goal of the battery test and management's is to use the full capacity of the device and to be able to see the need for changing the battery at the right time.

The increase in the number of electric appliances and electric vehicles also led an increase in the need of batteries recently. That situation affects every aspect of the daily life and healthy performance of batteries became even more important in terms of environmental security, efficiency and so on. Engineers have developed several solutions and technologies for these problems. Open-Circuit Voltage Measurement Method, Coulomb Counting Model and Kalman Filters are some examples. On the other hand State of Charge method helps us to get information about the health of the battery, However, all applications for the problem so far have been quite huge, inaccessible and hard to use. Since the batteries became an important of daily life more than ever, these applications are needed to be accessible, economic, precise and user-friendly.

The aim of the thesis is providing an affordable and user-friendly device by integrating mainly the Coulomb Counting Method with several others successfully. Using Raspberry in the device helps it to be accessible, economic, fast and adaptable to different interfaces. All the components that had been used in the device in this thesis have approximately from %1 to %5 error term and therefore quite precise about the estimations.

Today, the cost and the complexity of Battery Test and Management systems led waste of millions of batteries through ineffective usages. That harms the environment and economy of the world. The device that had been developed in this thesis, provides accessible, affordable with its 80$ price and user-friendly solutions for battery testing and management problems.

Keywords: BMS, SOC, end user friendly, Raspberry

Batarya Test ve Yönetim Sistemi

Özet

Bu tez, bataryalarla çalısan cihazlarda önemli problem ve ihtiyaçlardan olan batarya test ve yönetimi ile ilgilidir. Batarya test etmenin ve yönetmenin amaci, cihazlarımızdan beklenen performansı alabilmek ve batarya değişikliği gerektiren durumları belirleyebilmektir. Son zamanlarda artan elektrikli araç ve cihaz sayısı, bataryalara olan ihtiyacı arttırmış durumdadır. Hayatımızın her alanına etki eden bu durum, bataryaların sağlıklı çalışması ihtiyacını ve çevre güvenliği açısından, bataryaların korunumu konusunu daha da önemli hale getirmiştir. Artan ihtiyacı karşılamak üzere, son donemlerde çesitli metod ve teknolojiler geliştirilmiştir. Bu metodlardan bazıları, Açık Devre Voltaj Ölçme Metodu, Coulomb Counting Model ve Kalman Filtreleridir. Pilin Şarj Durumu (SOC) metodu da bataryaların sağlık durumu ile ilgili bilgi almamıza yardımcı olabilmektedir. Bu metodların kullanıldığı cihazlar, büyük, karmaşık ve dolayısıyla anlaşılması ve okunması zor olabilmektedir. Dünyanın her yerinden, her insanın günlük hayatında önemli bir parça haline gelen bataryalar ve dolayısıyla bataryaların testi ve yönetimi, günlük ihtiyaçlara cevap verebilen basitlik ve kullanışlılıkta olmalıdır.

Bu tezin amacı genel olarak Coulomb Counting ve diğer metodların entegrasyonu ile yapılmiş, etkili, ucuz ve kullanıcı dostu bir batarya test ve yönetimi cihazı geliştirmektir. Cihazda Raspberry kullanarak cihazımızı ulaşılabilir, ekonomik, hızlı ve çevre arabirimleriyle uyumlu olmas hedeflenmiştir. Tezde geliştirilen cihazda kullanılan ekipmanlar ve elektronik komponentlerin örnekleme düzeylerinin ortalama hata paylari %1 ile %5 arasında değişen, hassas kompanentlerden oluşmakta ve dolayısıyla son kullancıya, az hatal sonuç sunulmaktadır.

Günümüzde batarya test ve kontrol sistemlerinin maliyeti ve kullanım zorlugu, milyonlarca pilin efektif olmayan biçimlerde kullanılarak sağlıklarını kısa sürede yitirmesine sebep olurken, dünyaya, çevremize ve dünya ekonomisine negatif etkiler bırakmaktadır. Tezde geliştirilen batarya test ve yönetimi cihazı, 80$ maliyetiyle bu problemlere çözüm üretmekte ve ileri araştırmalar için Raspberry kullanımını ve model kombinasyonunun değerini ifade etmektedir.

Anahtar kelimeler: Pil yonetim Sistemi, Sarj Durumu, Kullanici Dostu, Raspberry

Acknowledgements

This study was supported by REPKON Machine and Tool Industry and Trade Inc.

I thank Assoc. Prof. Hakan Gürkan who is my project supervisor to always support me with his extensive knowledge in the all parts of the project. Also thanks my project Co-advisor Assoc. Prof. Ümit Güz.

Also, I thank to my parents Ali Berbergil, Meral Berbergil and my sister Seda Berbergil, who always support me with their love and patient.

Finally, I want to thank Özge Tokmak, Umur Güzel, Eren Ay, Efe Can Çoban, Ege Sarı who always make me feel never alone with their friendship, patience and help during the academic years.

To my beloved family…

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List of Abbreviations

ADC	**A**nalog to **D**igital **C**onversion
SOC	**S**tate of **C**harge
BMS	**B**attery **M**anagement **S**ystem
C-RATE	**S**cale-**I**nvariant **F**eature **T**ransform
DOD	**D**epth-of **D**ischarge
EVs	**E**lectric **V**ehicles
HEVs	**H**ybrid **E**lectric **V**ehicles
LI-ION	**L**ithium-**I**on
MOSFETs	Metal-**O**xide **S**emiconductor **F**ield-**E**ffect **T**ransistors-
OCV	**O**pen **C**ircuit **V**oltage
CIM	**C**urrent **I**ntegration **M**ethod
KF	**K**alman **F**ilter
DM	**D**irect **M**easurement
RBF	**R**adial **B**asis **F**unction
BP	**B**ack **P**ropagation

Chapter 1

Introduction

Significant increase in costs of fossil fuel and placement of environmental issues into scientific and politic agendas worldwide have caused improvements in energy storage systems. Batteries have become one of the most preferable among the energy storage systems due to the efficiency and environment friendliness. It is possible to underline several types of batteries that are being used for industrial purposes: lead-acid battery, NiMH battery, Ni-Cd battery, and Li-ion battery etc. Beyond the less pollution and high efficiency; higher working cell voltage, lesser autonomous discharge rate and better power density are some of advantages that batteries sustain. Small electric appliances, hybrid vehicles and smart appliances are the sectors in which the batteries are most needed and used.[1].

Li-ion batteries are one of the most supple battery types due to the high energy density, longer life cycle, high power density and lower self discharge rates that they provide. However the electrical performance of the Li-on battery is satisfactory in terms of energy density and C-Rate, some of the major obstacles are remained because of the non uniformity of the capacity and the retention ratio through aging. These given restrictions might be improved especially for the battery packs which are compound by the several serial connected battery cells. Therefore, the performance of energy storage can be optimized and protected by implementing a BMS (battery management system). Moreover, as the main determining factor of extending battery life, State of Health (SOH) and State of

Charge (SOC) can be determined by measuring the terminal voltage of a battery cell. Battery management system could be used not only to protect the battery from the overcharging and the over-discharging but to support the battery life[2].

SOC estimation is the most significant challenge for using batteries. In order to set controlling strategy for a battery, SOC can be described as the most important parameter.The battery performance can be analyzed with the help of SOC and it would not only prevent over discharge, protect the battery and help expanding the life cycle but would present opportunities to the user for making choices as well. Yet, all batteries include different chemicals and it is hard to access the combination of chemical within the battery Hence that, estimation of the SOC of a battery is not easy. Due to the parametric uncertainties and limitation of battery models, precise estimation of the State of Charge is complicated and hard to apply. Low precision levels and credibility of the estimation of SOC are the most common hardships in practicing in the industry. Moreover SOC and SOH may not be determined directly with measurement which is performed by the any electrical tool. On the other hand it is possible to estimate SOC and SOH by considering time variable voltage and charging- discharging current. It is possible to notice and compare advantages and disadvantages of the several methods to be able to estimate SOC and SOH in the academic field[3].

Data driven, adaptive and hybrid methods can be considered as three different categories of SOC estimation methods.[4]. Data driven methods consist of model base method and direct measurement which can be introduced by the coulomb counting method (CCM)[5], impedance method [6] and open circuit voltage(OCV) method[7].

Chapter 2

State of the Art Battery and the Parameters

In order to power electrical devices such as flashlights, smart-phones and electric cars, the batteries in which one or more electro-chemical cells are used.

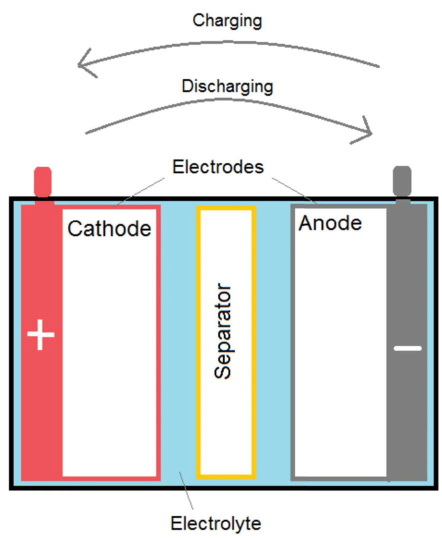

Figure 2.1: Illustration of Battery

A battery is made up of a few voltaic cells. Each cell consists of two uncompleted cells which are serially connected by a conductive electrolyte with metal cations.

Each half-cell has a standard-specific electromotive force (emf, measured in volts). The cell's net emf is nothing more than just the difference between its half-cell emfs. The electrical driving force across a cell's terminals is considered as the terminal voltage (difference) and is computed in volts.A cell's terminal voltage that has been neither charging nor discharging is named the open-circuit voltage and is equal to the cell's emf[8]. During the discharging phase the terminal voltage is lesser in magnitude than the time the battery does not discharging nor charging. So that in ideal batteries the internal resistance is insignificant, electromotive forces constant terminal voltage remains the same.[9].

Manufacturers of batteries are capable of understanding the needs of clients and therefore they responded with sustaining the best matches for specific applications. An example of smart adaptation is the mobile phone industry, where the level of small size, high energy density and affordability are emphasized. Some of the commonly used battery types can be listed as follows;

- **The Nickel Cadmium (Ni-Cd) Battery** The Ni-Cd chooses rapid charging for DC charging to slow charging and pulse charging.Other type of batteries rather than Ni-Cd are better with short discharge and middling levels of currents of load. Among the all types of batteries, Ni-Cd is a unique kind of battery that can perform successfully in harder conditions. It can stay connected to the charger for days and still can be used occasionally. Yet again, periodic full discharge would be helpful for Ni-Cd to keep its performance at peak for longer. Hence, Ni-Cd's are still most common in radios, medical devices and other tools in which rechargeable batteries are needed. New batteries with higher energy density and environment friendliness decreased the share of market for Ni-Cd batteries.

- **The Nickel-Metal Hydride Battery** These types of batteries can truly be considered as successful due to better energy density and Eco-friendly components that have been used. Compared to Ni-Cd, the modern NiMH represents up to 40% better energy density. It could even have higher capacity, yet the significance of possible side effects prevents that. It is considered that NiMH is inferior to the Ni-Cd. Service life decreases under certain conditions such as the cycling under heavy loading and storing at high temperature. The Nickel-Metal Hydride Battery undergoes from high self-discharge, that is significantly larger than the Nickel Cadmium batteries. In markets such as wireless communications and mobile computing, the NiMH replaced the Ni-Cd. The customer is encouraged to use NiMH instead of Ni-Cd batteries in many parts of the globe. That's due to environmental issues about the spent battery being carelessly disposed of. Experts say that the NiMH has improved significantly in recent years, however there are limitations. The most significant weaknesses of NiMH are the same with the ones with the Nickel Cadmium batteries. However, NiMH is considered as the gateway battery to the lithium battery technology.

- **The Lead Acid Battery** The Lead Acid Battery: This is the first commercially produced and sold rechargeable battery in the history of batteries. The main sectors that use this type of batteries are cars, trucks and huge uninterruptible power systems. Different kinds of these batteries were developed until 1980s in order to use for any purposes. One well known kind of these batteries is maintenance free lead acid batteries. The fluid electrolyte was transformed and the enclosure was sealed into moistened separators. Added safety valves to allow gas to be diffused during loading and discharge. Two battery designations emerged, driven by different applications. There are also two different kinds of lead acid batteries:

  - Small Sealer Lead Acid (SLA)
  - Large Valve Controlled Lead Acid (VRLA)

  SLA's are also called as Gel cell in the market due to the name of the company. In terms of the specifications of both batteries, they are identical. In contrast to the flooded lead acid battery, both SLA and VRLA are designed with low over-voltage potential to prevent the battery from reaching its gas-generating potential during charging. Excess charging would result in the depletion of gassing and water. Consequently, the full potential of these batteries can never be charged. The lead acid has not got a memory capability. Leaving the battery on float charging does not cause any damage for an extended period of time. Among the rechargeable batteries, its charging retention of the battery is the best. The time span for self-discharging for the NiCd batteries are three months for 40% their full capacity while the same capacity is being discharged in the SLA batteries in a year. Moreover, the Small Sealer Lead Acid batteries are cheaper to buy yet, when full cycles are continuously required, the operating cost may be more expensive than the Ni-Cd batteries. Unlike the Ni-Cd, the SLA should not be deep cycled. A complete discharge creates pressure and a small proportion of capacity is being destroyed in each cycle of the battery. This is also applicable for the other chemical components of batteries. The Small Sealer Lead Acid batteries are considered as being less dangerous than Nickel Cadmium batteries, yet they are also considered to be more harmful for the environment.

- **The Lithium Ion Battery** In the 1980s, efforts to develop rechargeable lithium batteries followed, but failed because of safety issues. Research shifted to a non-metallic lithium battery using lithium ions due to the inherent instability of lithium metal, particularly during charging. Even though the energy density is lower than lithium metal, the Liion is safe as long as certain precautions are met when charging and discharging. The Liion's energy density is generally twice the typical NiCd density. Advancements in electrode active materials have the potential to improve roughly three times the NiCd's energy density. The Liion is a low maintenance battery, which can't be claimed by many other chemistries. There is no memory and no scheduled cycling is necessary to extend the life of the battery. Moreover, the self-discharge opposed to NiCd is less than half, making the Liion suitable for modern fuel gage applications. When disposed of, Liion cells induce little damage. Liion also has its disadvantages as can be seen by its relative advantages. It is fragile and requires a circuit of protection to keep operation safe. The protection circuit, which is built into each pack, limits each cell's peak voltage during charging and protects the cell voltage from falling too low on discharge. Moreover, the temperature of the cell is monitored to avoid extreme temperatures.

- **Lithium Polymer Battery** Li-Po is slightly different from other types of electrolytes used in other battery systems. Going back at least to the 1970s, the original design employs a dry solid polymer electrolyte. This electrolyte resembles a plastic film not conducting electricity but allowing an ion exchange. The electrolyte works as a plastic film which allows ion interchange rather than conducting electricity. The dry polymer layout provides manufacturing, robustness, safety, and thin-profile geometry simplifications. The dry Li-polymer is unfortunately suffering from the lack of conductivity. As the modern communication devices and mobile computing equipment hard drives require current bursts, these batteries cannot sustain it due to the high internal resistance. Internal resistance is too high and can not deliver the current bursts necessary for modern communication devices and the mobile computing equipment hard drives. The introduction of the Liion polymer battery has been deferred by technical issues and delays in manufacturing. Furthermore, the Liion polymer's proposed superiority still has not been realized. The need of extensive and comprehensive protection of lithium polymer batteries from external factors such as water, portability becomes an important disadvantage for them. Portability is a must especially for companies that produce portable, small electronic devices such as tablets and smart phones..

The capacity is used to define the energy storage capability of the battery. During the charge or discharge operations, battery capacity is reduced because of the reduction in the active materials both for the anode and cathode. The effect of the capacity decrease can be calculated not only considering the laboratory measurements but also with the offline analysis. One of the most convenient analysis method can be seen as OCV-SOC curve which tries to define battery aging degree. According to the [10] it is possible to visualize the figure 2.1 SOC-OCV and in this method, the battery should be charged or discharged fully at the given low rate. However, described methods are not time efficient so that online estimation of the battery aging is not always reliable.

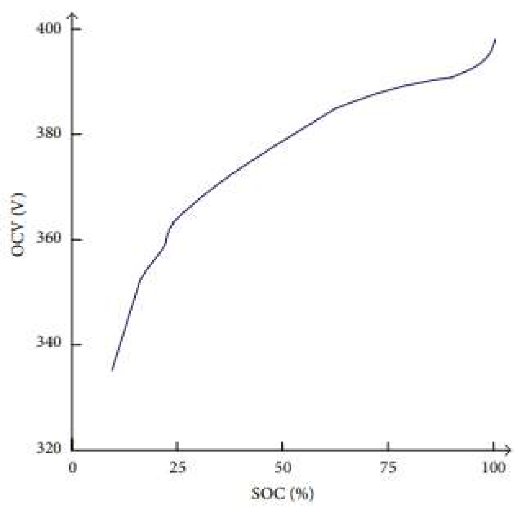

Figure 2.2: SOC-OCV

One may present an alternative solution for the estimation problem, it is possible to introduce incremental capacity analysis which is derived from the lithium intercalation process[11]. Incremental capacity analysis is very sensitive approach especially when the change is so slow in the battery aging sense[12].

As it was mentioned above, the SOC presents the most important parameter for batteries, yet the definition of it also assesses many problems. The most common definition of the share of battery's current capacity in the nominal capacity is the commonly used definition for the SOC of a battery. The nominal capacity of a battery can be found in its document that presented by its producers and it shows the maximum amount of charge that is allowed to be stored in the battery. The State of Charge can be defined as follows;

$$SOC_{(t)} = \frac{Q_{(t)}}{Q_n}$$

With respect to the methodology, there are various mathematical formulas for the estimation that are classified. These classifications of the State of Charge estimation methods differ in various literatures. Literature [4] allows us the divide into four categories represented in the figure 2.2 SOC.

2.1 (DM) Direct Measurement

Direct measurement methods use some physical indicators of a battery like the potential differences between positive and negative terminals and internal resistance. There are different direct measurement methods that have been applied such as open circuit voltage method, terminal voltage method, impedance measurement method, and impedance spectroscopy method.

2.1.1 Terminal Voltage Method

The method relies on the voltage decreases between terminal pins of the battery since the battery creates internal impedance while discharging and therefore, the EMF (electromotive force) of a battery is comparable to the voltage in the terminal. The electromotive force of a battery is more or less linear comparable to the SOC as well. The EMF of battery is approximately linear proportional to the SOC, therefore the terminal voltage of battery is approximately linear proportional to the SOC as well. At various discharge currents and temperatures, the terminal voltage method has been employed. However, the estimated error

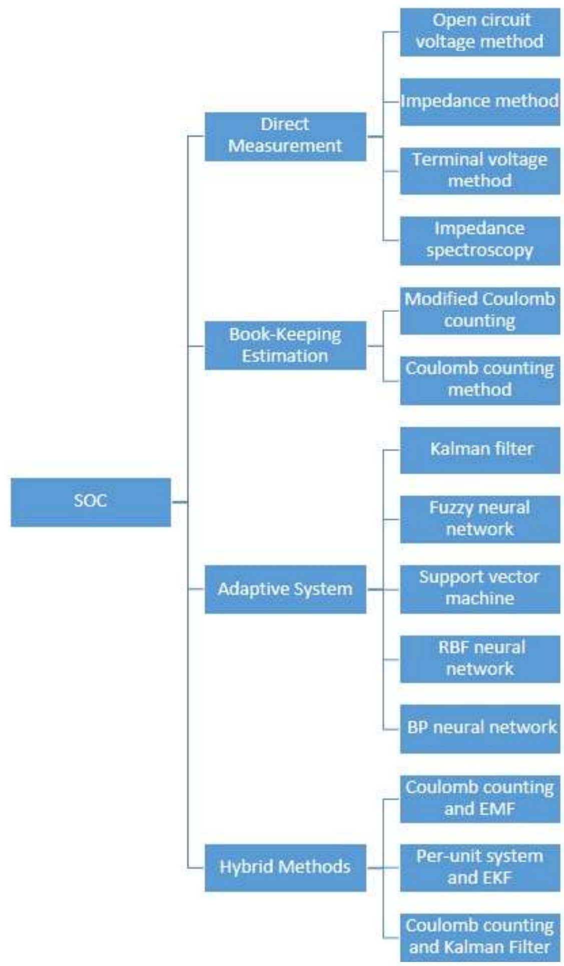

Figure 2.3: SOC

found large since the terminal voltage of battery quickly drops at the end of the process of discharge [13].

2.1.2 Open Circuit Voltage Method

A proper mathematical model can be derived by using the open circuit voltage which is measured from the battery open circuit voltage.

The association between lead-acid batterys SOC and its OCV is roughly linear.

$$V_{OC(t)} = a_1 \times SOC_{(t)} + a_0,$$

In the given equation above, SOC(t) represents the SOC of the battery at time t, a0 is the terminal voltage of the battery when SOC = 0%, and a_1 is taken from the known value of a_0 and Voc(t) at SOC = 100%. On this equation, estimated value of the SOC equals to the estimated value of the OCV [14]. If the batteries are disconnected from the loads longer than two hours, the OCV method on the OCV of batteries would be proportional to the SOC. Yet, this disconnection period might be unnecessarily long for implementing the battery[15].The varying battery terminal voltage change can be defined as the exponential character through the charge or discharge operations[16]. It is known that the OCV method requires enough rest time to be ensured about the accuracy The Li-ion batteries do not have a linear relationship between the OCV and SOC, on the other hand [17], The relationship between OCV and SOC for a Li-ion battery can be seen in Figure 2.2. The association of OCV with SOC of a battery can be found by performing a pulse load which eventually let the battery to reach the balance [18]. That relationship between the Open Circuit Voltage and State of Charge is not same for all battery types. Therefore, the SOC should be estimated accurately. In that sense, [19] suggests an improved OCV-SOC association over the conventional ocv-soc. They used the dual extended Kalman filter to estimate the SOC and the capacity of a Li-ion battery.

2.1.3 Impedance Method

Within the techniques which have been employed so far, this one provides information for several parameters. Among these parameters, the magnitudes might be depending on the SOC of the battery. Even though the parameters for the impedance and the changes of them within the SOC are not special for all storage unit systems, it implies a requirement for a wider experiments of impedance to identify and usage of parametric impedance for calculating the SOC of the battery at hand [20].

2.1.4 Impedance Spectroscopy Method

This is a method in which battery impedances over a sufficient range of ac frequencies at various charge and discharge currents can be measured. Statistical methods such as least-squares fitting can be used to find the measured impedance values in the values of the model impedances. Therefore SOC can be indirectly inferred with measuring the present battery impedances and associating them with the known impedances at the various SOC levels [21].

2.2 Book Keeping Estimation

The input data is the battery discharging current for the book-keeping estimation method. This method covers internal battery effects such as self-discharge and discharging efficiency, capacity loss and so forth. There are two different type of book-keeping estimation used so far;

- Coulomb counting
- Modified Coulomb counting method

2.2.1 Coulomb Counting Method

The CCM Approach can be performed by measuring the discharging of a battery through current over time and also by making an I-t integration to derive an estimation of SOC[5]. CCM has some disadvantages which are directly related with the accuracy of the current sensor and the error is increased gradually because of the open loop nature.The method relies in the formula given below [14];

$$SOC(t) = SOC_{(t-1)} + \frac{I_{(t)}}{Q_n}\Delta(t)$$

2.2.2 Modified Coulomb Counting Method

Due to the imprecision of measured discharging current, a new method is developed with corrected current. This method provides better precise measurement and thus, more precise and accurate estimation of SOC. The relationship between the corrected current and discharging current of a battery is quadratic. Through the experimental data, the method was developed by using the formula given below ;

$$Ic(t) = k_2 I(t)^2 + k_1 I(t) + k_0,$$

K2, k1 and k0 are determined as a result of experimental data and they are all constant values. Therefore, SOC is being estimated with the equation given below [14]:

$$SOC(t) = SOC_{(t-1)} + \frac{Ic_{(t)}}{Q_n}\Delta(t)$$

Data that had been obtained through experiments show that modified coulomb counting method provides better results than the conventional coulomb method.

2.3 Adaptive System

As it is described in the[22], since these systems are self-designed, they can be adjusted to the changing environments. SOC estimation based on nonlinear SOC affected by the chemical factors. Therefore, they are responsive to the nonlinear nature of SOC and changing factors of chemicals under different conditions. However some of the good solutions are offered thanks to the adaptive method. Discharging conditions can be adopted through these adaptive approaches which combines Kalman Filter(KF), Support Vector Machine(SVM), Neural Network, etc. Kalman Filter is commonly used in the adaptive filter technique [23]. It is required to verify real time state estimation in order to have valid SOC estimation when Kalman Filter method is adopted[24].

2.3.1 Kalman Filter

Obtaining the measurement road data as real-time variables to estimate the SOC of battery might cost too much due to the complexity. In [24], it is shown that how Kalman filter method can sustain verifiable estimations of SOC with the real-time state estimation. In the [25], developed a Kalman filter SOC estimation method for lithium-ion batteries. They find that, Kalman filter is a valid and effective method. In the [26] it is suggested that, practicing the voltage and the current analysis in the terminal, an improved version of Kalman filter might help to estimate the concentrations of chemicals in the battery for obtaining the SOC precisely. In [27], a new and different SOC estimation method is shown which relies in Unscented Kalman Filter (UKF) theory and presents a comprehensive battery model. In the battery State of Charge estimation, the findings suggest that UKF is better in terms of precision and accuracy than the extended Kalman filter method. In the [28], developed an adaptive UKF method which estimates SOC of a lithium-ion battery for electric vehicles which use battery.

2.3.2 Fuzzy Neural Network

A fuzzy neural network is a kind of machine learning which looks for the parameters of a fuzzy system by using a likeness techniques from neural networks. Fuzzy systems might be used for solving questions such as pattern identification, regression and so on. They are especially good for answering questions where no mathematical model was proposed, Neural networks and fuzzy systems are quite useful when they are successfully combined. While neural networks include several algorithms yet provides no interpretation and implementation, fuzzy systems lack of learning while provides simple interpretation and implementation[29].

2.3.3 Support Vector Machine

The support vector machine (SVM) was used in various pattern recognition domains for classification. The SVM was also introduced for regression problem, even the problem of regression intrinsically more challenging than the problem of classification. The SVM presents better estimations than OLS in terms of robustness since the OLS is not capable of capturing small changes [30].In the [30] examined the use of an SVM to estimate the lithium-ion battery SOC. The estimator based on SVM removes the Coulomb counting SOC estimator disadvantages, in addition to that it produces precise SOC estimates.

2.3.4 RBF Neural Network

The Radial Basis Function (RBF) neural network for systems with insufficient information is a effective estimation approach. The relationships between one main (reference) sequence and the other relative sequences in a particular set can be analyzed. The neural RBF network was used in the estimation of SOC. The technique has been examined using data from battery experiments. Findings suggest that the estimation model's operating speed and estimation accuracy can meet the requirements in practice, and the model has some application value

[31]. The SOC estimation approach of the RBF neural network employs terminal voltage input data, discharge current and battery temperature to estimate the LiFePO4 battery SOC under different discharge conditions. It is found that the experimental data are in similar agreement.

2.3.5 BP Neural Network

The most popular method in artificial neural networks is the neural back propagation (BP) network. Due to their good capability of nonlinear mapping, self-organization, and self-learning, the BP neural network is introduced in SOC estimation [14]. As described by the problem, the input-target relationship is non-linear and very complex in the SOC estimate [32]. The artificial neural network-based SOC indicator uses the recent past of voltage, current and battery ambient temperature to predict the current SOC. BP's neural network architecture comprises a hidden layer an output layer and input layer. For terminal voltage, discharge current, and temperature, the input layer has 3 neurons, the hidden layer has g neurons, and the output layer already has one neuron for SOC [17].

2.4 Hybrid System

The hybrid models are popular since they combine good features of each method and optimum estimation performance. As it is obvious, each method has different advantages, therefore hybrid models provide opportunity to the engineers to be able to use different models for the purposes of the project. That way, it increases the available information and help it to integrate to the measurement. In the literature, for SOC estimation it is found hybrid models provide good results [33].

2.4.1 Coulomb Counting & EMF

As it the name refers, this method combines coulomb counting and EMF measurement during equilibrium state and book-keeping estimation as the discharge state has been developed and applied in a real-time estimation system [33]. We know that a battery loses capacity during the cycling. Therefore, a simple Qmax adaptation algorithm is developed in order to estimate SOC and calculate remaining run-time (RRT) and finally to improve the SOC estimation for coping with the aging effect.

2.4.2 Per Unit System & EKF

In the [34] defined the use of an EKF in combination with a per-unit (PU) system to identify suitable battery model parameters for high accuracy SOC estimation of a degraded lithium-ion battery.In addition to terminal voltage and current, the absolute values of the parameters in the equivalent circuit model are transformed into dimensional values compared to a set of base value to qualify the battery model parameters differed by the aging effect based on the PU system.

2.4.3 Coulomb Counting & Kalman Filter

Put forward a new variation of soc estimation method called as Kalman AH method[35] . As used in the coulomb counting method, this method uses Kalman filter method for fixing the initial value.through this method , Kalman filter estimates approximate initial value to integrate to its true value.afterwards,the Coloumb counting method is used to calculate the SOC for long working time[35]. As a result of comparing with the real SOC attained from a discharge test,they found out SOC estimation error is 2.5%.since it had 11.4% estimation error this is superior to Coloumb counting method

2.5 Alternative Approach:Model Based

A proper mathematical model is very critical, especially when it comes in to the accuracy of the SOC estimation. Since the model is used to set the output which is SOC characteristic by implemented restrained battery signals.Besides,for the use of identify correctly the external characteristics of Lithium-ion(Li-ion) battery nonlinear models are proposed. The nonlinear estimation algorithms and online parameter identification methods are necessary to make sure the preciseness of the model based soc estimation with nonlinear battery models. Some of the two commonly used battery models can be given such as:electrical and electrochemical models. Even though electrical model based estimation have a flimsiness such that the model parameters can only applicable for the new cells not for the aged ones.

2.6 The Future of SOC Estimation

As energy storage systems in mobile electronic devices and vehicles that use electric as any portion of energy source have been reported, SOC's estimated accuracy is becoming extremely valuable. Many scientists have did a lot of research on estimating SOC in recent decades. Accuracy estimates have been gradually improving, and extensive research and development efforts can be expected. According to the [14], some of the future steps can be advised in order to maintain developed efficient estimations such as;

- Doing additional research on combined methods like combination of direct measurement method with bookkeeping estimation method to produce more accurate SOC estimation results.
- in various kinds of batteries, current estimation approach can be used. Doing additional research on the practical implementation of fundamental methods.

- Some more research on developing the capacity of the SOC estimation system to deal with the battery's aging impact.
- Research further novel strategies of artificial intelligence and develop their training algorithms to obtain SOC's estimated accuracy. Moreover, the concentrate of future research is on new methods on complicated work space.
- Doing extensive research on the estimation of the adaptive parameter. The models have the ability to cope to different types of batteries, varying discharge conditions, and different aged batteries instantly.
- Determine a more precise assessment system and SOC performance estimation standard.

Chapter 3

Hardware & Software Implementation

3.1 Introduction to Raspberry

Raspberry Pi's size is 5.5cm x 8.5cm and low cost computer that has CPU, GPU, input and output pins, USB ports and many other peripherals that helps to run many operations as standard computer. First Raspberry Pi generation was released in 2012, to make it easier for students to learn computer systems.

For the Battery Test and Management system, some of the important concepts can be introduced as follows;

- **Linux Operating System (OS):** System on board structure helps us to integrate the interface and software parts to each other. With the help of the Linux OS, we do not need low level languages and the program performs all the hardware processes while the Linux OS performs the necessary OS duties. As it is known, watch dog structures are needed in case of the times when the programs freeze in integrated systems, however our code does not need those systems and provides uncut and stabile performance for the process. Linux OS provides necessary implementation of Wi-Fi and Bluetooth without needing extra softwares. It also provides X-Graphic Environment in which no other graphical interface is needed to perform for graphical purposes. Therefore, it becomes user-friendly and requires no additional knowledge or effort. Since Java Virtual Machine can be used on Linux OS, it does not require high level language in any kind. Hence that, JVM provides a stable and smooth environment for work. It also sustains more flexibility for beckend codings.

- **Multi core and On board Graphics:** Broadcom BCM 2837B0 quad-core A53 (Armv8) 64bit 1.4GHz soc.With multi core it can handle more than one processes at the same time. It is superior to the MCU's in terms of speed and process power. With the on board chip it has, FULL HD quality screening is possible without using the processor.Integrated compact card 4 core arm process power, GPU, Wi-Fi, ram, Ethernet Bluetooth, USB, GPIO etc are all in a card at the size of a credit card.

- **Communication Capabilities:** Such as Wi-Fi, Ethernet, Bluetooth. It includes various communication hardware and protocols. Therefore remote control is possible to the device and it is so easy.Gigabit Ethernet (10/100/1000),2.4 and 5 GHz 802.11 b/g/n/ac. For the Bluetooth 4.2.Since the computer is small and affordable, the structures meet its goals and it is easy to reach its elements. The device is commonly-used and its hardware provides adaptability for various equipment to connect and use. Ready to use 40 pin GPIO (General Purpose Input Output): I2C, 2 SPI, UART, 4 USB 2.0, CSI Camera Port, DSI Display Port, Composite audio, video output, HDMI output.

- **Massive Storage:** Due to the USB and the micro SD card on the device, it provides massive storage for the users. Micro SD card can be up to 32 GB. Therefore the results of the tests can be stored on the device without needing any computer.

- **Ram:** With the 1 GB LPDDR2 SDRAM, the device has high capacity to run the processes without needing any additional RAM. Therefore RAM is not a problem for our design. That helps us to run the program without a problem while it also provides a smooth place for IO operations.

- **Price:** With a 35$ price tag it is very easy to obtain.
- **Disadvantages:** It does not work in real time. While the programs on the hardware uses Kernel, applications run on the Linux. Therefore, the program does not run on real-time like the programs on the hardware which work with nanoseconds. However, it does not affect the results since that much sensitivity is not needed for our purposes. Huge power consumption because of the number of hardware and high process power, it requires 5v and 2.5A current.

3.2 Electronic Circuit Design

For some additional features we might need to specialize the outputs on the raspberry. For instance, in order to make digital measurement, analog to digital converter, for current control: MOSFET's, for temperature control and monitoring; heat sensors, for reading the current: current sensors, these all can be fastly integrated to the Raspberry with the help of the 40 pins over the device.

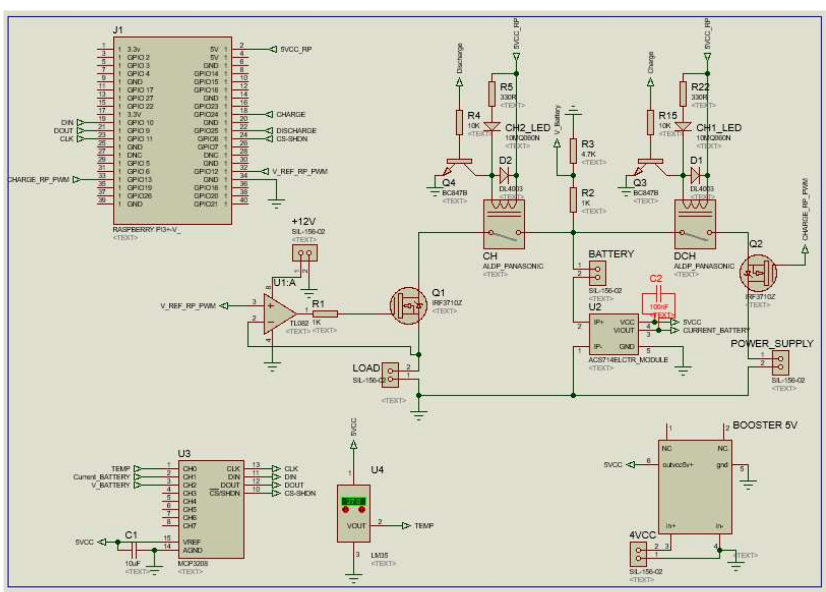

Figure 3.1: Circuit Design Screen

3.3 User Friendly Interface For Testing

We will discuss about the screen that we designed here. The easiness of all parameters and processes that a user might need is significant on our screen. The details about the outlook and functions will be given below.

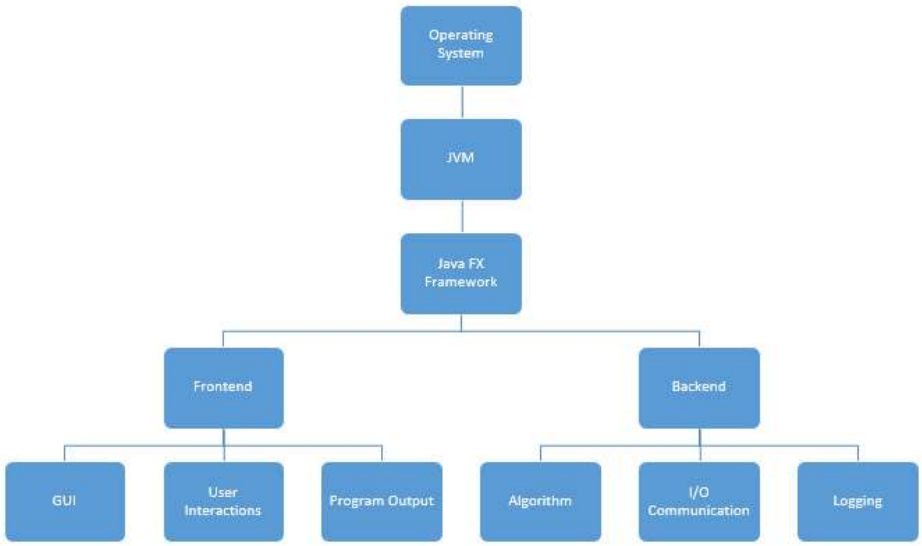

Figure 3.2: System Design Screen

Figure 3.3: Battery Information Screen

3.3.1 Battery Information Screen

In this screen figure 3.3, the user provides the categorical information. An ID is assigned to the battery. All data regarding the battery is stored in this system based on the ID.

- **Battery ID:** The system automatically assigns a numeric ID to the battery.
- **Battery Type:** It refers to the chemical structure of the battery.
- **Voltage:** It refers to the nominal voltage of the battery.
- **Capacity:** It refers to the value of the capacity for the battery.
- **Discharge Rate:** It refers to the nominal discharge value and it is expressed with C constant.
- **Max. Discharge rate:** Discharge Rate: It refers to the maximum discharge value with C-Rate function.

- **Charge Rate:** It refers to the nominal charge value with C-Rate function again.
- **Max. Charge Rate:** It refers to the maximum charge value with C-Rate.

3.3.2 Battery Charge Parameters Screen

Figure 3.4: Battery Charge Parameter Screen

On this screen, the information related to the charging that would be used on the battery can be applied. With respect to the information, the charging takes place.

- **Charge Rate:** It refers to the amount of current that will be applied during the charge with C-Rate.
- **End Voltage:** It refers to the maximum voltage that will be applied to the battery during the charge
- **Max. Test Time:** During the test of the battery, it refers to the maximum time span. When it exceeds, it will give time-out error.

- **Max. Test Temperature:** During the test, it refers to the maximum heat. If it exceeds this value, the system will give temperature error.

3.3.3 Battery Discharge Parameters Screen

Figure 3.5: Battery Discharge Parameter Screen

On this screen, the information related the discharge test requirements will be applied. With respect to the given information, the test begins.

- **Discharge Rate:** The value of current that will be applied during the charging over the factor of C-Rate
- **End Voltage:** It refers to the required minimum voltage of the battery during discharging application.
- **Max. Test Time:** Test Time: During the test of the battery, it refers to the maximum time span. When it exceeds, it will give time-out error.
- **Max. Test Temperature:** Test Temperature: During the test, it refers to the maximum heat. If it exceeds this value, the system will give temperature error.

3.3.4 Battery Test Screen

Figure 3.6: Battery Test Screen

- **Start Charge Test:** It starts the required process of test for charging.
- **Start Discharge Test:** It starts the required process of test for discharging.
- **Start Combined Test:** It starts the required process of test for charging and discharging. If the box of charge first is not marked, it will automatically start the combined test with discharging as default.
- **Charge First:** If the check box is marked, combined test will begin with charging.
- **Pause Test:** It pauses the test. The user can continue.
- **Stop Test:** It stops the test.
- **Live Statics:** It provides instant data about the test.

- **Battery Type:** It shows the type of the battery which is given from the catalog.
- **Elapsed Time:** It shows the time since the beginning of the test.
- **Voltage:** It shows the instant voltage between batterys terminals.
- **Current:** It shows the instant current between batterys terminals.
- **Temperature:** It shows the temperature of the battery through a sensor over the battery.
- **Estimated Charge Percentage:** By considering the value from the catalog, it shows the load factor of the battery based on the value obtained during the 2nd stage of the combined test.
- **Testing:** It occurs if everything is okay, it will not if there is something wrong about the test.
- **Fault:** It is passive if everything is okay, otherwise it lights on.

3.3.5 Battery Live Screen

According to data mentioned above, it shows the values over time on a graphic.

- **Voltage** When the voltage toggle button is marked, the user will receive graph of the voltage of the battery over time that have been obtained during the test.
- **Current** When the current toggle button is marked, the user will receive a graph of the current of the battery over time that have been obtained during the test.

Figure 3.7: Battery Live Screen

- **Temperature** When the temperature toggle button is marked, the user will receive a graph of the temperature of the batter over time that been obtained during the test.
- **Estimated Capacity** When the estimated capacity toggle button is marked, the user will receive a graph of the sum of the all currents on the battery in a second that have been obtained during the test.

Figure 3.8: Battery Result Screen

3.3.6 Battery Result Screen

- **Battery ID:** It is a numeric ID assigned by the system automatically.
- **Battery Type** The kind of the battery entered to the system.
- **Measurement Error:**A static data about the error term.
- **Most Effective Voltage Range:** It takes into account the critical points between two highest slopes of the capacity curve that appear during the combined test.
- **Measured Total Capacity:** It shows the measured total capacity.
- **Minimum Discharge Rate:** It refers to the minimum discharge rate which is given before the test for the test conditions.
- **Max Discharge Rate:** It refers to the maximum discharge rate which is given before the test for the test conditions.
- **Min. Charge Rate:** It refers to the minimum charge rate which is given before the test for the test conditions.

- **Max. Charge Rate:** It refers to the maximum discharge rate which is given before the test for the test conditions.
- **Start Voltage:** The value of voltage between the terminals of the battery that is measured at the initial point of the test.
- **End Voltage:** The value of voltage measured at the end of the test.
- **Total Test Time:** Total time that test takes place.
- **Min. Temperature:** The minimum value of temperature that measured at the surface of the battery during the test.
- **Max. Temperature:** The maximum value of temperature that measured at the surface of the battery during the test.

3.4 Analog to Digital Converter

Due to the fact that there is no analog input on Raspberry module, we used MCP-39208 which is an analog to digital converter. This module helps us to convert analog values into digital in between 50-100 ksps illustration speed and up to 12-bit resolution rate. With this smooth conversion of analog values into digital ones, MCP-39208 provides readable formats for the users. The communication within the module is provided through SPI communication protocol. There are 8 channels analog input on the MCP-3208. In order to determine the value of the inputs correctly, this module needs a reference voltage. We use this pin by energizing it through a stable sensitive source.

3.5 Current Measurement

Through ACS-714 sensor, one might measure the current over the battery during the charge and discharge as Hall effect.

It has the features of 5 micro seconds output rise time in response to step input current 80 kHz bandwidth and Total output error 1.5% typical, at TA = 25C . Its current reading capacity is +/-30 A.

3.6 PCB Design

By connecting this card in to the raspberry i/o pins, we can have a unit which is capable to do all given processes. In the Figure 3.9 PCB 3-D View can be visualized and also in the figure 3.10 layout of the designed PCB can be noticed.

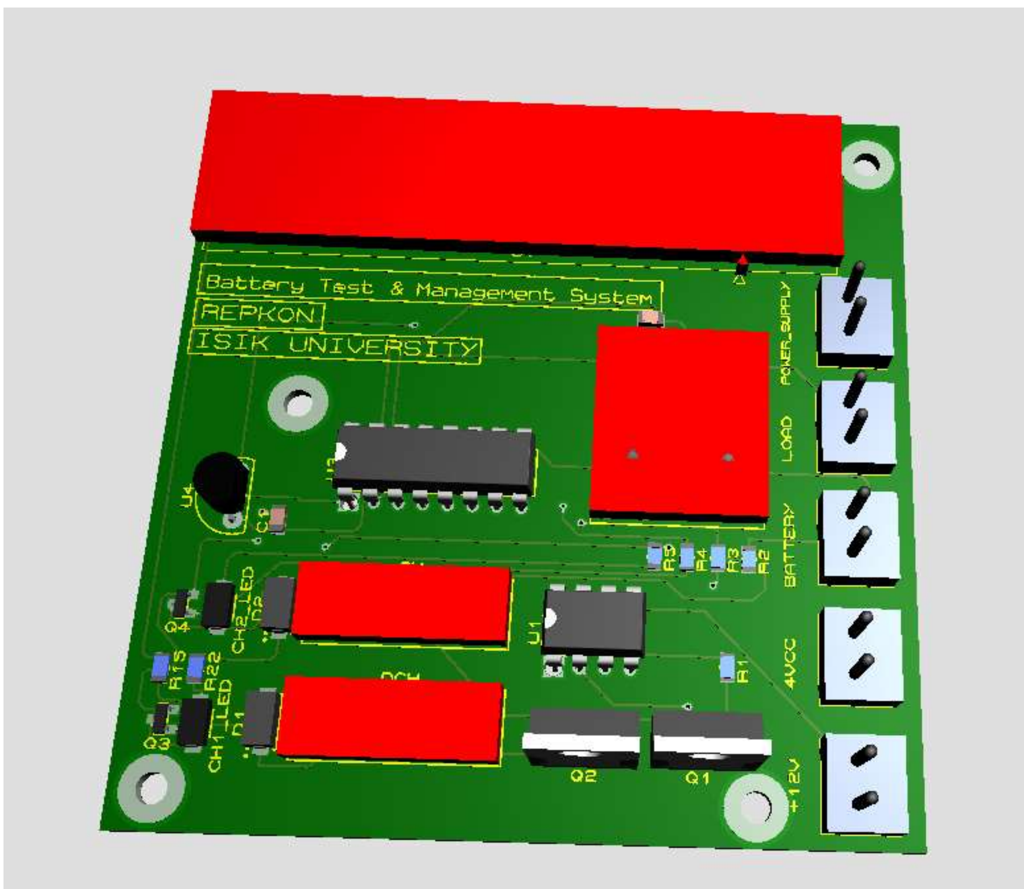

Figure 3.9: PCB 3-D View

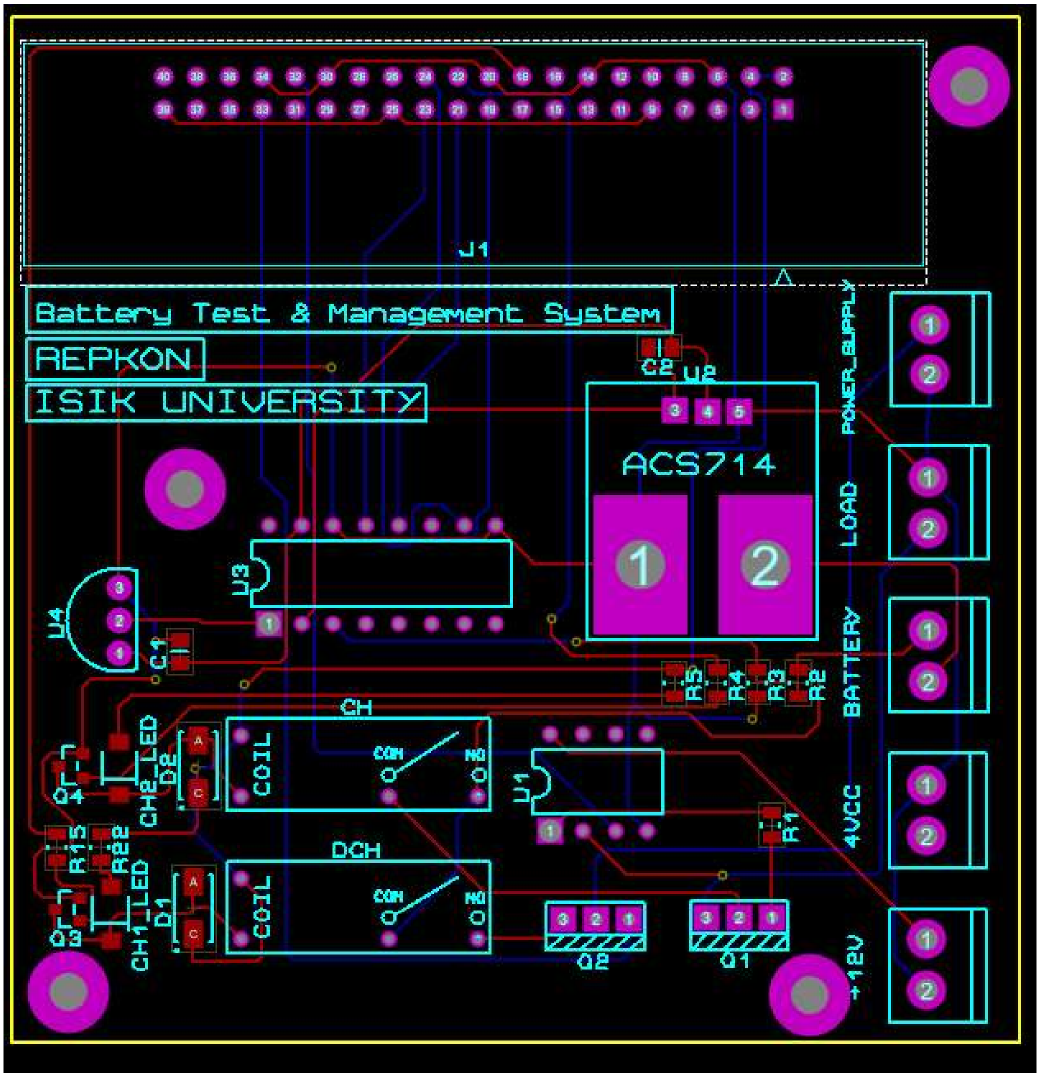

Figure 3.10: PCB Layout Screen

Chapter 4

Result And Conclusion

Increasing demand for batteries with the increasing number of electric appliances and vehicles lead an increasing need for battery test and management systems for both industrial and personal uses. In that sense, I should underline several types of batteries that are being used in industries: Ni-MH battery, Ni-Cd battery, and Li-ion battery etc. As the li-ion batteries presents high energy density, longer life cycle, high power density and lower self-discharge rates, they are very popular for battery users from all kinds. However, non-uniform structure of Li-Ion batteries and the retention ratio through aging present a set of challenges for the users. These restrictions might as well be taken care of for the battery packs with a efficient battery management system implemented. BMS does not only protect the battery but also support the battery life. As it was mentioned before, most of the products for testing and managing the batteries are not capable of meeting significant part of the needs for the users. Therefore, with this project I have developed a user-oriented battery tester to target the end users and realized the necessary test scenarios. The charge and discharge processes are applied, and the current flow values can be read with the device developed here. This helps users to determine the rate of battery charge. Hence, the user can now see the actual capacity of the battery and the maximum reachable voltage range. All the data is being evaluated together with a range of outputs by means of the determined algorithm.

In the Chapter 2, the thesis aims on understanding the state of art of the battery and the parameters to measure the efficiency. A few voltaic cells constitute a battery basically. Through a conductive electrolyte uncompleted cells of a battery are connected in a standard battery. Each semi-cell has a standard-specific electromotive force (emf, measured in Volts). The cells net emf is nothing more than just the subtraction of one pair of cells emf from the other. In order to calculate the driving force across a cells terminals, we use the terminal voltage. Manufacturers of batteries are capable of understanding the needs of clients and therefore they responded with sustaining the best matches for specific applications. An example of smart adaptation is the mobile phone industry. The level of small size, high energy density and affordability are emphasized. Some of the commonly use battery types can be listed as follows;

- The Nickel Cadmium (Ni-Cd) Battery
- The Nickel-Metal Hydride Battery
- The Lead Acid Battery
- The Lithium Ion Battery
- Lithium Polymer Battery

Given the variety of the battery types, in Chapter 2, the thesis focused on the different methods for calculation of performance and estimation of efficiency.

The Chapter 3 focuses on the implementation of hardware software system on to the device. That starts with the most significant part of the system; Raspberry. Raspberry Pi size is 5.5cmx8.5cm and low-cost computer that has CPU, GPU, input and output pins, USB ports and many other peripherals that helps to run many operations as standard computer. First Raspberry Pi generation was released in 2012, for learning computers systems easy for students. Later, the chapter emphasized the important concepts of battery test and management system such as Linux Operating System, Multi core and On board Graphics, Communication Capabilities, Massive Storage, Ram and affordable price. Among them, with Raspberry, Linux Operating System provides many opportunities. System on board structure helps us to integrate the interface and software parts to each other. With the help of the Linux OS, we do not need low level languages and the program performs all the hardware processes while the Linux OS performs the necessary OS duties. As it is known, watch dog structures are needed in case of the times when the programs freeze in integrated systems, however our code does not need those systems and provides uncut and stabile performance for the process. Linux OS provides necessary implementation of Wi-Fi and Bluetooth without needing extra software. It also provides X-Graphic Environment in which no other graphical interface is needed to perform for graphical purposes. Therefore, it becomes user-friendly and requires no additional knowledge or effort. Since Java Virtual Machine can be used on Linux OS, it does not require high level language in any kind. Hence that, JVM provides a stable and smooth environment for work. It also sustains more flexibility for backend coding.

Moreover, in order to have some additional features, a specialized output on the raspberry has been developed for the device. For instance, in order to make digital measurement, analog to digital converter, for current control: MOSFET's, for temperature control and monitoring; heat sensors, for reading the current: current sensors, these all can be fast integrated to the Raspberry with the help of the 40 pins over the device. Due to the fact that there is no analog input on Raspberry module, we used MCP39208 which is an analog to digital converter. This module helps us to convert analog values into digital in between 50-100 ksps illustration speed and up to 12-bit resolution rate. With this smooth conversion of analog values into digital ones, MCP39208 provides readable formats for the users. The communication within the module is provided through SPI communication protocol. There are 8 channels analog input on the MCP3208. In order to determine the value of the inputs correctly, this module needs a reference voltage. We use this pin by energizing it through a stable sensitive source.

Many steps of this project have previously been used alone in special products. In the case of this project, all of these steps are collected in one device, and all these individual steps are customized for these operations. Given all these situations, there is no competitive substitute of this product Therefore, it will be considered as an innovative product. As the device can successfully take the outputs of all these measurements mentioned above and analyses as a single result in a easier way, the project is successful. All of these features, on the other hand, are very important in terms of making faster and more accurate decisions and building the infrastructure for future projects. Today, the cost and the complexity of Battery Test and Management systems sled waste of millions of batteries through ineffective usages. That harms the environment and economy of the world. The device that had been developed in this thesis, provides accessible, affordable with its 80 US dollars price and user- friendly solutions for battery testing and management problems.

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Appendices

Appendix A

Source Code

```
package batterymanagementsystem;
import batterymanagementsystem.gpio.MCP3208GpioProvider;
import com.jfoenix.controls.JFXToggleButton;
import com.pi4j.gpio.extension.base.AdcGpioProvider;
import com.pi4j.gpio.extension.mcp.MCP3208Pin;
import com.pi4j.io.gpio.GpioController;
import com.pi4j.io.gpio.GpioFactory;
import com.pi4j.io.gpio.GpioPinAnalogInput;
import com.pi4j.io.spi.SpiChannel;
import java.io.BufferedWriter;
import java.io.File;
import java.io.FileOutputStream;
import java.io.FileWriter;
import java.io.IOException;
import java.io.OutputStreamWriter;
import java.text.DecimalFormat;
import java.util.HashMap;
import java.util.Map;
import java.util.Random;
import java.util.logging.Level;
import java.util.logging.Logger;
import javafx.application.Platform;
import javafx.event.ActionEvent;
import javafx.scene.chart.XYChart;
import javafx.scene.control.Toggle;
import javafx.scene.control.ToggleButton;
enum TestType {
    DISCHARGE, CHARGE
}public class BatteryTest {    private AdcGpioProvider provider;
    final GpioController gpio = GpioFactory.getInstance();
    private GpioPinAnalogInput inputs[] = new GpioPinAnalogInput[3];
    private TestType tt;
    private Battery battery;
    private long startMillis;
    private int maxTestMinute;
    private int maxTestTemperature;
    private int endVoltage;
    private FXMLDocumentController caller;
    private double vref = 4.972;
    private int runThread = -1; // -1 stop, 0 pause, 1 run    private HashMap<String, String> batTemps = new HashMap<String, String>();
    private HashMap<String, String> batCurrs = new HashMap<String, String>();
    private HashMap<String, String> batVolts = new HashMap<String, String>();    public BatteryTest(FXMLDocumentController caller, TestType tt, Battery battery, int maxTestMinute, int maxTestTemperature) {
        this.maxTestTemperature = maxTestTemperature;
        this.maxTestMinute = maxTestMinute;
        this.tt = tt;
        this.battery = battery;
        this.caller = caller;        try {
            provider = new MCP3208GpioProvider(SpiChannel.CS0);
        } catch (IOException ex) {
            Logger.getLogger(FXMLDocumentController.class.getName()).log(Level.SEVERE, null, ex);
        }        inputs[0] = gpio.provisionAnalogInputPin(provider, MCP3208Pin.CH0, "0");
        inputs[1] = gpio.provisionAnalogInputPin(provider, MCP3208Pin.CH1, "1");
        inputs[2] = gpio.provisionAnalogInputPin(provider, MCP3208Pin.CH2, "2");        Thread t = new TestThread();
        startMillis = System.currentTimeMillis();
        runThread = 1;
        t.start();    }    public void stop() {
        runThread = -1;
    }    public void pause() {
        if (runThread == 1) {
            runThread = 0;
        } else {
            runThread = 1;
        }
    }    private double readBatTemp() {
        double DAC = provider.getValue(MCP3208Pin.CH0);
```

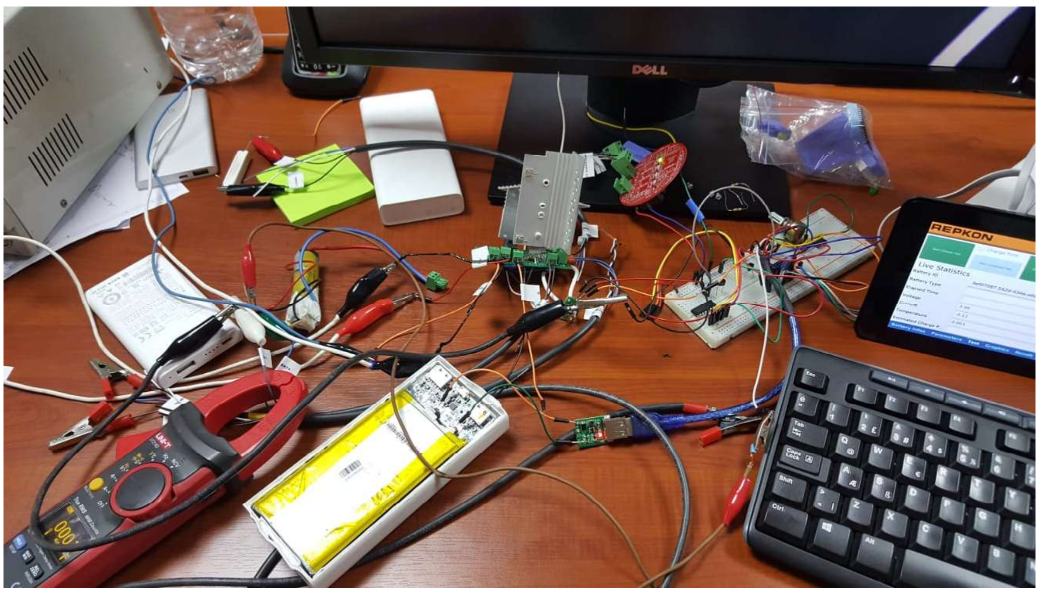
```java
    double DAC = provider.getValue(MCP3208Pin.CH0);
    double voltage = DAC * vref / 4070;
    return ((int) (voltage * 10 * 10 * 100)) / 100.0;
}    private double readCurrent() {
    double DAC = provider.getValue(MCP3208Pin.CH1);
    double voltage = DAC * (vref / 4070);
    double current = ((voltage - (vref / 2)) / 0.066);
    return ((int) (current * 100)) / 100.0;
}    private double readVoltage() {
    double DAC = provider.getValue(MCP3208Pin.CH2);
    double voltage = DAC * vref / 4070;
    return ((int) (voltage * 100)) / 100.0;
}    class TestThread extends Thread {        @Override
    public void run() {
        double capacity = 0;
        XYChart.Series voltage_series = new XYChart.Series();
        voltage_series.setName("Voltage");            XYChart.Series current_series = new XYChart.Series();
        current_series.setName("Current");            XYChart.Series temperature_series = new XYChart.Series();
        temperature_series.setName("Temp");            XYChart.Series capacity_series = new XYChart.Series();
        capacity_series.setName("Capacity");
        Platform.runLater(new Runnable() {                @Override
            public void run() {
                caller.getGraphics_graph().getData().clear();
                caller.getGraphics_graph().setCreateSymbols(false);
                caller.getGraphics_graph().setAnimated(false);                caller.getGraphics_toggle_voltage().setOnAction((ActionEvent e) -> {
                    if (caller.getGraphics_graph().getData().contains(voltage_series)) {
                        caller.getGraphics_graph().getData().remove(voltage_series);
                    } else {
                        caller.getGraphics_graph().getData().add(voltage_series);
                    }
                });                caller.getGraphics_toggle_current().setOnAction((ActionEvent e) -> {
                    if (caller.getGraphics_graph().getData().contains(current_series)) {
                        caller.getGraphics_graph().getData().remove(current_series);
                    } else {
                        caller.getGraphics_graph().getData().add(current_series);
                    }
                });                caller.getGraphics_toggle_temperature().setOnAction((ActionEvent e) -> {
                    if (caller.getGraphics_graph().getData().contains(temperature_series)) {
                        caller.getGraphics_graph().getData().remove(temperature_series);
                    } else {
                        caller.getGraphics_graph().getData().add(temperature_series);
                    }
                });                caller.getGraphics_toggle_estimated_capacity().setOnAction((ActionEvent e) -> {
                    if (caller.getGraphics_graph().getData().contains(capacity_series)) {
                        caller.getGraphics_graph().getData().remove(capacity_series);
                    } else {
                        caller.getGraphics_graph().getData().add(capacity_series);
                    }
                });            }            });            long currentTime = System.currentTimeMillis();            double maxTemp = 0;
        double minTemp = 0;            double temp = readBatTemp();            double startVolt = readVoltage();
        double volt = readVoltage();
        double curr;
        boolean run = true;
        long starttime = System.currentTimeMillis();
        int i = 1;
        while (run && (currentTime - startMillis < maxTestMinute * 60 * 1000) && (temp < maxTestTemperature)) {
            while (runThread == 0) {
                try {
                    Thread.sleep(100);
                } catch (InterruptedException ex) {
                    Logger.getLogger(BatteryTest.class.getName()).log(Level.SEVERE, null, ex);
                }
            }            if (runThread == -1) {
                return;
            }
```

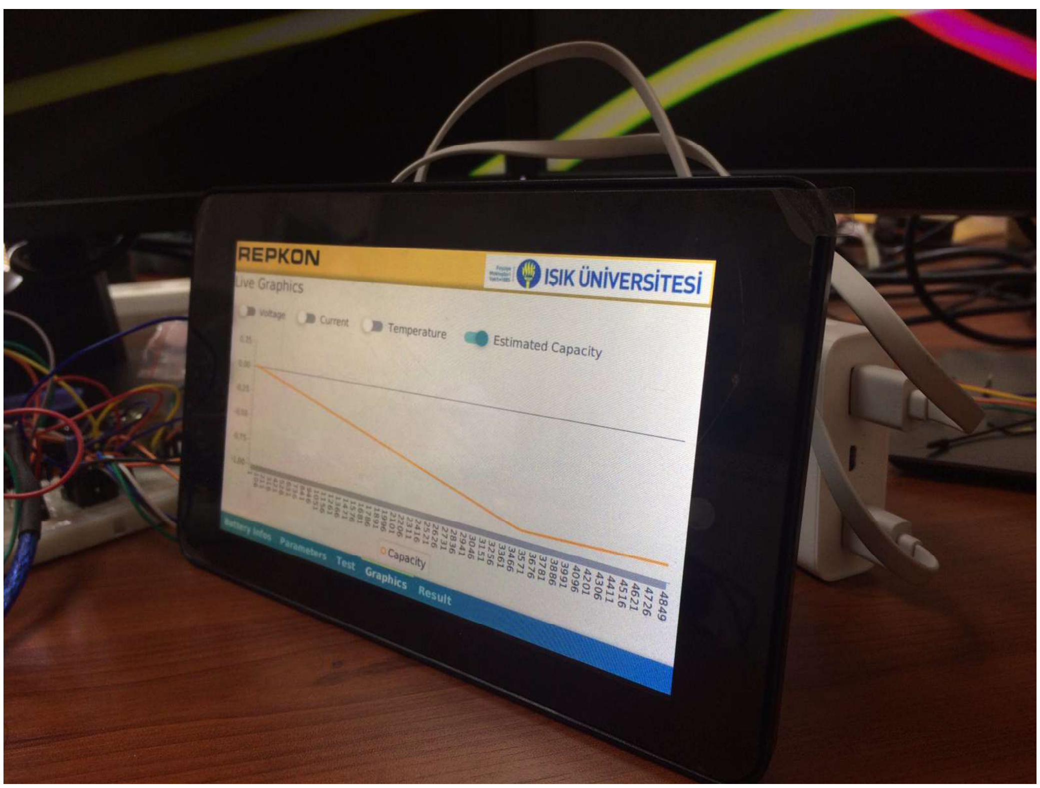
```java
            }
            currentTime = System.currentTimeMillis();
            temp = readBatTemp();
            volt = readVoltage();
            curr = readCurrent();
            if (tt == TestType.CHARGE) {
                if (volt > endVoltage) {
                    run = false;
                }
            } else if (tt == TestType.DISCHARGE) {
                if (volt < endVoltage) {
                    run = false;
                }
            }
                        if (temp > maxTemp) {
                maxTemp = temp;
            }
            if (temp < minTemp) {
                minTemp = temp;
            }

            String a="";
                        a=a+volt;
                        a=a+",";
                        a=a+curr;
                        a=a+",";
                        a=a+temp;

                        try {
                            writeFile1(a);
                        } catch (IOException ex) {
                            Logger.getLogger(BatteryTest.class.getName()).log(Level.SEVERE, null, ex);
                        }            final String fc = "" + curr;
            final String fv = "" + volt;
            final String ft = "" + temp;
            Platform.runLater(() -> {
                caller.getTest_current().setText(fc);
                caller.getTest_temperature().setText(ft);
                caller.getTest_voltage().setText(fv);
                caller.getTest_elapsed_time().setText("" + ((System.currentTimeMillis() - starttime) / 1000 / 60) + ":" + ((System.currentTimeMillis() - starttime) % (1000 * 60)) / 1000);            });            final double fdc = curr;
            final double fdv = volt;
            final double fdt = temp;


            capacity = capacity + fdc / 3600;

            final double capa = capacity;            try {
                String dt = "" + i;
                Platform.runLater(new Runnable() {            @Override
                    public void run() {
                        System.out.println(fdc);
                        voltage_series.getData().add(new XYChart.Data(dt, fdv));
                        current_series.getData().add(new XYChart.Data(dt, fdc));
                        temperature_series.getData().add(new XYChart.Data(dt, fdt));
                        capacity_series.getData().add(new XYChart.Data(dt, capa));



                    }            });
                Thread.sleep(1000);
                i++;            } catch (InterruptedException ex) {
                Logger.getLogger(FXMLDocumentController.class.getName()).log(Level.SEVERE, null, ex);
            }
        }        caller.getResult_battery_id().setText("" + battery.getBatteryID());
        caller.getResult_battery_type().setText("" + battery.getBatteryType());
```

```
        caller.getResult_battery_type().setText("" + battery.getBatteryType());
        caller.getResult_end_voltage().setText("" + volt);
        caller.getResult_max_charge_rate().setText();
        caller.getResult_max_discharge_rate().setText();
        caller.getResult_max_temp().setText("" + maxTemp);
        caller.getResult_measured_capacity().setText();
        caller.getResult_measurement_error().setText("5%");
        caller.getResult_min_charge_rate().setText();
        caller.getResult_min_discharge_rate().setText();
        caller.getResult_min_temp().setText("" + minTemp);
        caller.getResult_most_effective_voltage_range().setText();
        caller.getResult_start_voltage().setText("" + startVolt);
        caller.getResult_test_time().setText("" + ((System.currentTimeMillis() - starttime) / 1000 / 60) + ":" + ((System.currentTimeMillis() - starttime) % (1000 * 60)) / 1000);        }
    }

    public static void writeFile1(String line) throws IOException {
        try
{
    String filename= "Log.txt";
    FileWriter fw = new FileWriter(filename,true);
    fw.write(line+"\n");
    fw.close();
}
catch(IOException ioe)
{
    System.err.println("IOException: " + ioe.getMessage());
}
}}
```

Appendix B

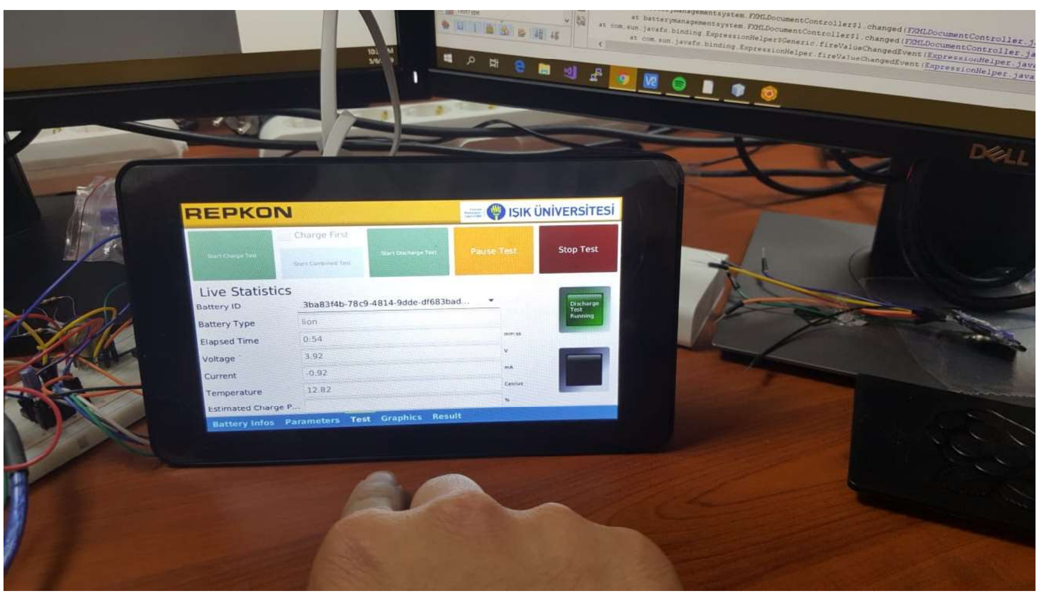
Practical Implementation




REPKON
IŞIK ÜNİVERSİTESİ
Live Graphics
Voltage
Current
Temperature
Estimated Capacity
Capacity
Battery Infos
Parameters
Test
Graphics
Result


HDMI
CAMERA
GCT
GCT

		Pin no.			
DC Power	3.3V	1	2	5V	DC Power
SDA1, I²C	GPIO 2	3	4	5V	DC Power
SCL1, I²C	GPIO 3	5	6	GND	
GPIO_GCLK	GPIO 4	7	8	GPIO 14	TXD0
	GND	9	10	GPIO 15	RXD0
GPIO_GEN0	GPIO 17	11	12	GPIO 18	GPIO_GEN1
GPIO_GEN2	GPIO 27	13	14	GND	
GPIO_GEN3	GPIO 22	15	16	GPIO 23	GPIO_GEN4
DC Power	3.3V	17	18	GPIO 24	GPIO_GEN5
SPI_MOSI	GPIO 10	19	20	GND	
SPI_MISO	GPIO 9	21	22	GPIO 25	GPIO_GEN6
SPI_CLK	GPIO 11	23	24	GPIO 8	SPI_CE0_N
	GND	25	26	GPIO 7	SPI_CE1_N
I²C ID EEPROM	DNC	27	28	DNC	I²C ID EEPROM
	GPIO 5	29	30	GND	
	GPIO 6	31	32	GPIO 12	
	GPIO 13	33	34	GND	
	GPIO 19	35	36	GPIO 16	
	GPIO 26	37	38	GPIO 20	
	GND	39	40	GPIO 21	



Curriculum Vitae

Rifat Berbergil was born on 3 October 1991, in Konya. He received his BS degree in Electrical and Electronics Engineering from Işık University in 2016 . He was participant a project in Işık University for Alternative Energy Car Racing . He is currently working as a specialist at REPKON Machine and Tool Industry.