Neural Network Based State of Charge (SOC) Estimation of Electric Vehicle Batteries

J.A.K.S. Jayasinghe, K.K.K.D. Nadishan

Department of Electronic and Telecommunication Engineering, University of Moratuwa, Sri Lanka

Abstract- Accurate estimation of state of the charge (SOC) is vital for electric vehicle batteries. This paper presents a novel method to estimate the SOC based on a neural network which can be programed into a low cost microcontroller. The microcontroller monitors the battery voltage and takes four samples immediately after the battery is disconnected from the load and monitors the steady state terminal voltage when the vehicle is parked for more than 30 minutes to train a neural network. Each time the battery is disconnected from the load while driving, the microcontroller takes four voltage samples to estimate the SOC using the previously trained neural network. In order to increase the accuracy, the battery temperature is also taken as an input.

Index Terms- Battery State of Charge, Electric Vehicle, Microcontroller, Neural Network

I. INTRODUCTION

Depleting fossil fuel sources made researchers to look for alternative energy sources to meet the ever increasing transportation needs. Hydrogen fuel powered vehicles, battery powered electric vehicles are two major new technologies. Plug-in Electric Vehicles, Hybrid Electric Vehicles are already in the market. Toyota Prius and Honda Insight are popular hybrid electric vehicles. Tesla Roadster and Nissan Leaf are plug-in electric vehicles but their popularity is not as good as Toyota Pruis or Honda Insight. Major reasons for this are high price, limited range and prolong charging time. In hybrid electric vehicles, range is enhanced by a gasoline engine and hence charging time is not a crucial issue. As hybrid electric vehicles use gasoline engines which runs at much better fuel economy, researchers have found a solution only to reduce the demand on fossil fuel. Using renewable energy sources such as solar, wind or bio mass for charging plug-in electric vehicles is a long lasting permanent solution for depleting fossil fuel sources. There are many issues yet to be solved to make such a solution as a viable replacement for fossil fuel. Batteries having very high energy densities, quick charging time and reliable estimate of remaining battery capacity are few such issues related the batteries used in plug-in electric vehicles. In a gasoline powered vehicle, a variable resistor actuated by a floater is sufficient to drive the fuel gauge fixed on the dash-board. Such an indicator gives a very reliable estimate of the remaining amount of fuel and hence driver can refuel his vehicle to reach his destination. Estimating the remaining capacity of a battery is not a simple as above. Getting a very reliable estimate of the remaining battery capacity is very important for electric vehicles as the battery recharging time is high compared to the gasoline refueling time.

Pang et al. [3] proposed an algorithm for estimating the SOC through an extended Kalman filter by measuring the terminal voltage and discharge current. The extended Kalman filtering is computational incentive algorithm and is not suitable for vehicles. Sato and Kawamura [6] proposed an algorithm based on the least square error method by measuring the terminal voltage and internal resistance estimated by a current impulse. This method could not handle the reduction of the SOC due to aging of the battery.

This paper propose a technique to get a reliable estimate of the SOC only estimating the steady-state open-circuit voltage by measuring the battery voltage immediately after the load is disconnected and estimating the steady-state open-circuit voltage using a neural network. The network is trained each time the battery reaches its steady-state open-circuit voltage using the back propagation algorithm. The open-circuit voltage is measured immediately after the load is disconnected and subsequently there more samples are taken at regular intervals under no-load condition. These four measurements with the battery temperature are taken for estimation of the SOC. The algorithm continues to measure the open-circuit voltage and if the battery reaches the steady-state open-circuit voltage the neural network is retained.

II. ESTIMATION OF SOC

Lead acid, Nickel cadmium, Nickel metal hydride and Lithium ion batteries are the most popular batteries used in electric vehicles. Out of these battery types, lead acid batteries are the cheapest while lithium ion batteries have the highest volumetric energy density (300 Wh/liter) and gravimetric energy density (125 Wh/kg). Further lithium ion batteries create least amount of hazardous waste during disposal. Therefore, many manufacturers of cheap electric vehicles such as electric scooters are using lead acid batteries while lithium ion will be most the prominent battery in future electric vehicles.

For lead acid and lithium ion batteries, open-circuit voltage is considered as an accurate indicator of the battery SOC following charge or discharge process provided sufficient time is allowed to stabilize the chemicals in the battery. For a lead acid battery, the SOC is linearly dependent on open-circuit voltage and specific gravity of the battery electrolyte. The steady-state open-circuit voltage (*E*) of a lead acid battery and specific gravity (*SG*) of the electrolyte is given by [5]:

$$E = SG + 0.84$$

The SOC and steady-state open-circuit voltage is given by [1]:

$$SOC = aE + b$$

where a and b are two constants determined by voltages of full and zero capacities. For lead acid battery the steady-state open-circuit voltage varies between 1.93 to 2.18 volts per cell approximately form 10%-100% SOC and it takes more than 30 minutes to reach the steady-state open-circuit voltage. The parameters a and b vary with the battery age.

For a lithium ion battery, the steady-state open-circuit voltage varies between 3.4 -4.1 volts per cell approximately form 10%-100% SOC [4], and the battery shows a dual gradient linear relationship from 10%-70% and 70% -100% with two different gradients. The battery takes more than 20 minutes to reach its steady state open circuit voltage after charging or discharging. In Lithiated Nickel Oxide (NCA) batteries, a single gradient linear relationship between the steady-state open circuited voltage and SOC extending from 10-100% [2].

If the vehicle is stopped for more than 30 minutes the battery will reach the steady-state open-circuit voltage and a very good estimate for the SOC can be obtained. However our attempt is to obtain an accurate SOC estimate while the vehicle is in use. Due to obstacles such as heavy traffic, traffic signals, road bends etc. it is usual that driver temporary takes the foot off the accelerator paddle. In case of an electric vehicle, this will disconnect the battery from the motor load and hence battery open-circuit voltage can be measured. In our proposed method, open-circuit voltage is measured at four regular sampling instants and a trained neural network is used to obtain an accurate estimate of the SOC. The neural network is trained every time the vehicle is stopped for more than 30 minutes.

Figure 1 depicts the proposed SOC estimation algorithm. A sampling clock activates the algorithm to measure the battery voltage and current at regular intervals and computations are activated when the current drawn from the battery reaches zero. The algorithm stores the open-circuit battery voltage *V(nT)* for initial four samples and a trained neural network is used to compute the SOC and update the display. The sampling interval is in the order of 1 second and hence every time the load current is disconnected for more than 4 seconds, the SOC display is updated. The algorithm continues to measure the open-circuit voltage to find the stead-state open-circuit voltage. When the measured open-circuit voltage remains constant for few measurements under no-load condition, algorithm decides that sufficient time has elapsed and battery has reached it's steady-state open-circuit voltage. This measured open-circuit voltage with the previously measured initial four samples is a training data set. Using this training data set, neural network is re-trained. This retraining process occurs every time the driver stops the vehicle for more than 30 minutes and hence the reduction of the battery capacity due to aging is taken into account. As the battery SOC is also depends on the battery temperature, battery temperature is also measured and used as an input for the neural network.

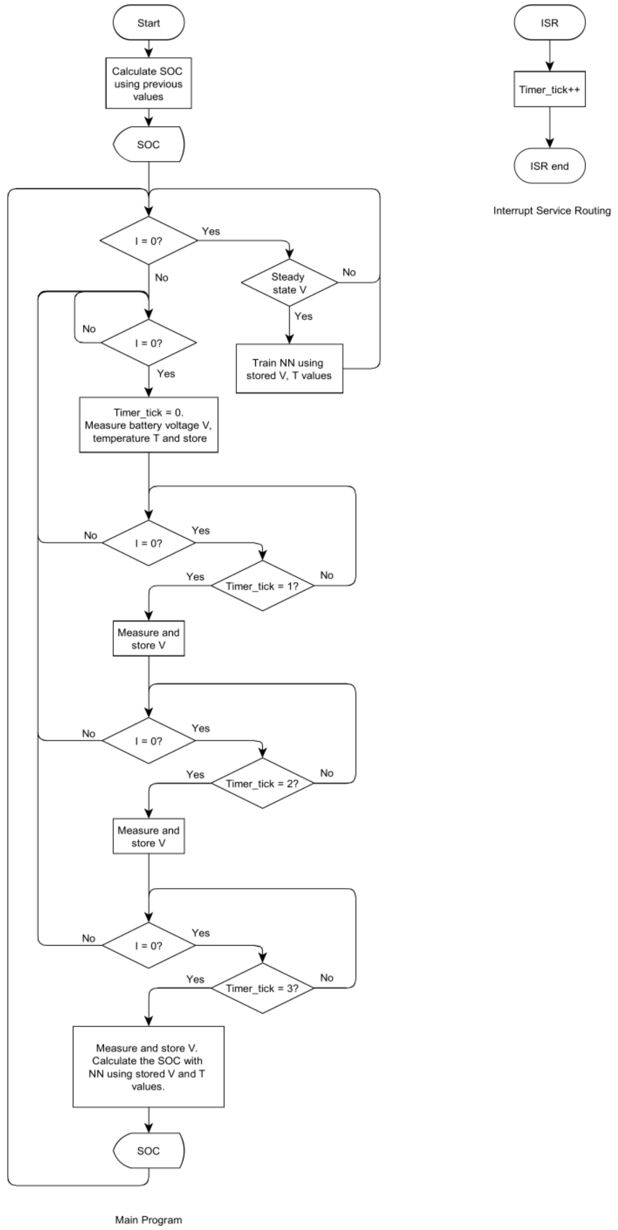

Figure 1: Algorithm Flow Chart

Figure 2 depicts the block diagram of the neural network with five input nodes, one output node and hidden layer with six nodes. Our studies have reveal that only five input nodes and hidden layer with six nodes are sufficient to get a SOC estimate with 1% accuracy, whereby entire algorithm can be coded into a low cost microcontroller.

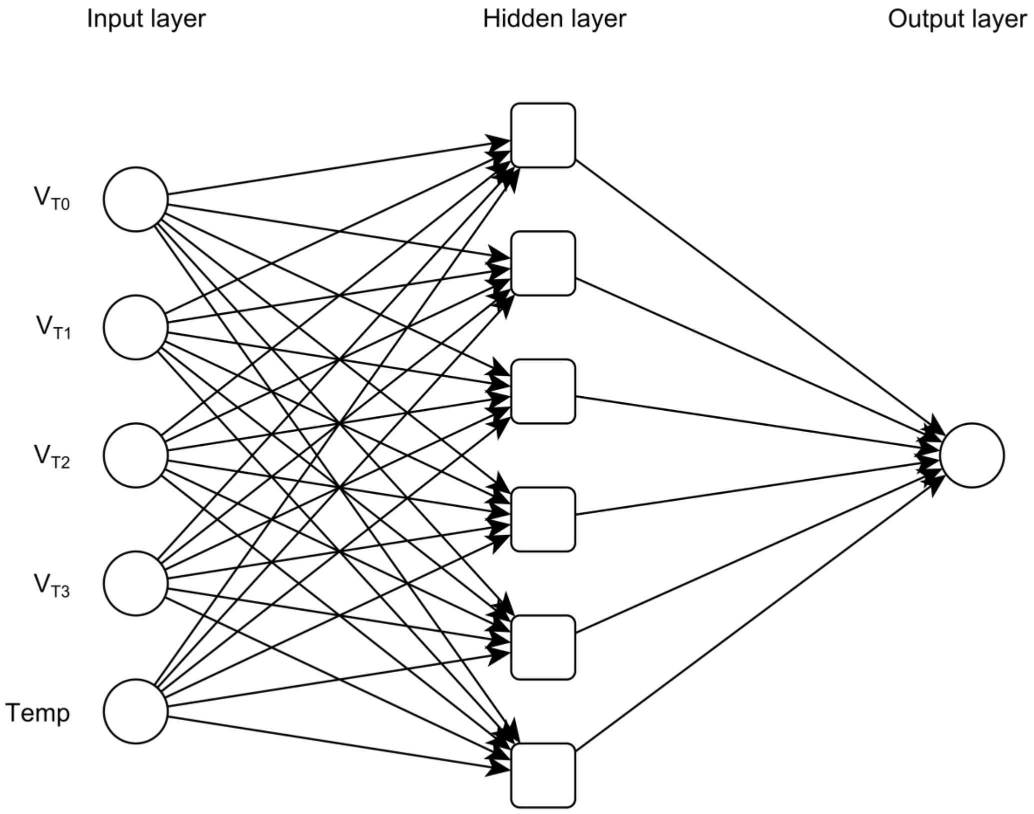

Figure 2: Neural Network

III. IMPLEMENTATION

The block diagram the SOC estimator based on ATMega88PA microcontroller is depicted in Figure 3. It has three analog input ports to measure the battery voltage, current and temperature. It has a 96x65 dot matrix display to display the battery SOC with other relevant parameters such as degree of aging. Further, there is an analogue output indicating the SOC. As battery current is measured, the unit containing the microcontroller and dot-matrix display is fixed closed to the battery while the analog display is fixed on the dash-board. The detailed block diagram of the main controller is depicted in Figure 4. The inputs are low pass filtered and fed to three analog input ports of the micro controller. An 8-bit output port drives the LCD display. The analog display is driven by a wire-pair and a PWM signal having an average DC value proportional to the SOC is generated by the microcontroller.

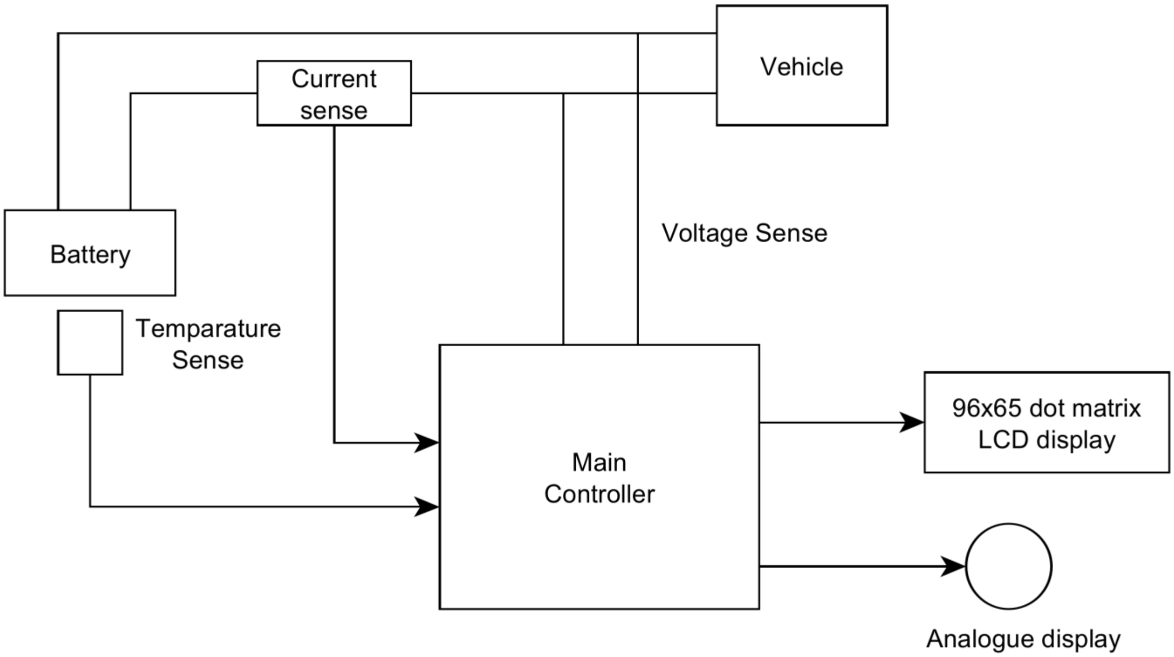

Figure 3: System Block Diagram

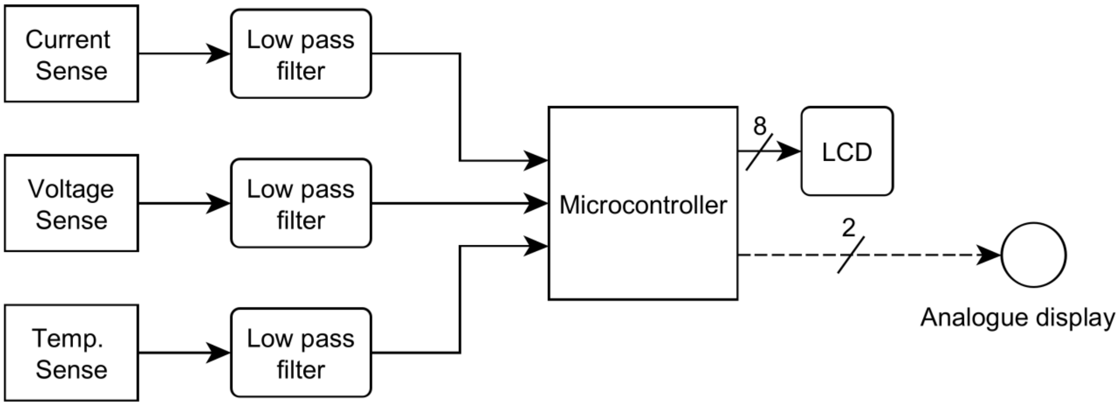

Figure 4: Main Controller Block Diagram

The photograph in Figure 5 shows the prototype implementation. Due to the simplicity of the algorithm the code is stored in a low cost microcontroller containing 8 kbytes program memory, 512 bytes EEPROM for storing data, 3 timer-counters for program flow control. The cost of the prototype is Rs. 2000/= and hence can be used even with low-end electric vehicles such as electric scooters.

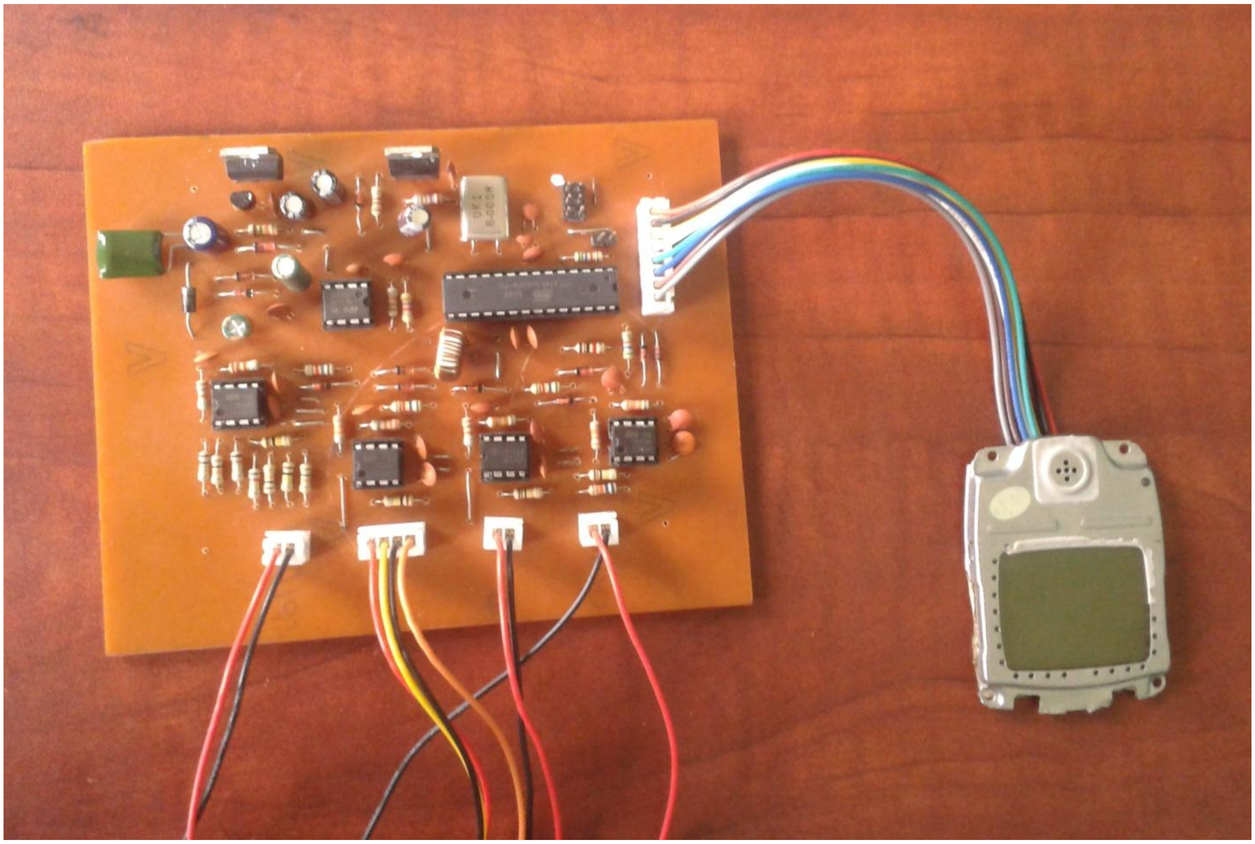

Figure 5: Photograph of the prototype

IV. CONCLUSION

A neural network based algorithm and its implementation on a low-cost microcontroller for getting very reliable estimate of the SOC of lead acid and lithium ion batteries used in electric vehicles is presented. The simplicity of the algorithm makes it possible to implement the system using a low cost microcontroller while the robustness of the algorithm make it possible to get a very reliable estimate for the SOC even taking the battery aging and temperature effects.

REFERENCES

[1] D. Linden and T.B. Reddy, Handbook of Batteries, Mc-Graw-Hill Book Company, 2002.

[2] J. McDowall, Understanding Li-Ion Technology, Proceeding of Battcon 2008, pp 9-1 9-10.

[3] S. Pang, J. Farrell, J. Du and M. Barth, “Battery State of Charge Estimation”, Proceedings of the American Control Conference 2001, pp 1644-1649.

[4] A. Rahmoun and H. Biechl, “Modeling of Li-Ion Batteries using Equivalent Circuit Diagrams”, Przeglad Elektrotechniczny (Electrical Review) 2012”, pp 152-156.

[5] D. Rand, R. Wood and R. Dell, Batteries for electric vehicles, John Wiley and Sons, 1998.

[6] S. Sato and A. Kawamura, “A New Estimation Method of SOC using Terminal Voltage and Internal Resistance for Lead Acid Battery”, Proceedings of the Power Conversion Conference 2002, pp 565-570.

AUTHORS

First Author – J.A.K.S. Jayasinghe, Ph.D. Senior Professor, Department of Electronic and Telecommunication Engineering, University of Moratuwa, Sri Lanka, jaks@ent.mrt.ac.lk**Second Author** – K.K.K.D. Nadishan, B.Sc. Eng., Research Assistant, Department of Electronic and Telecommunication Engineering, University of Moratuwa, Sri Lanka

Correspondence Author – J.A.K.S. Jayasinghe, jaks@ent.mrt.ac.lk, kapjaya608@gmail.com, +94-777-688894