State of Charge and State of Health Estimation of the Electric Vehicle Batteries

Centre for Mechatronics and Hybrid Technology
Mechanical Engineering McMaster University

Farzaneh Ebrahimi

EECOMOBILITY (ORF) & HEVPD&D CREATE

Battery Management System

- It is increasingly apparent that Electrical Vehicles (EVs) are transitioning into one of the most important methods of transportation within 21st century; batteries are the main components that have made this progression feasible.

- A Battery Management System (BMS) is an energy management control strategy that is designed to

    - Communicate with other onboard subsystems
    - Monitor the battery states
    - Control Charge and discharge
    - Thermal management
    - Cell balancing
    - And, safety

Estimation Strategies

- Considering the fact that battery SoC has a time-varying and nonlinear characteristic, and can be affected by aging, temperature, and the like, SoC estimation approaches can be divided into three main categories: direct measurement method, SoC estimation method using the black box battery model, and the SoC estimation method based on the state space battery model
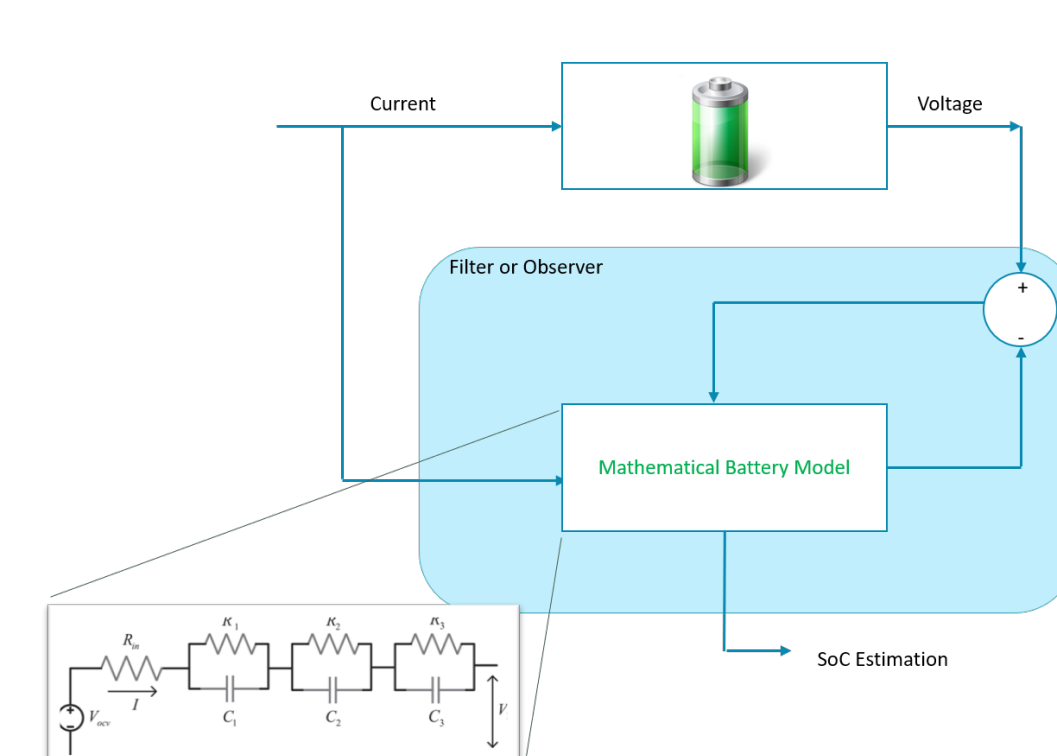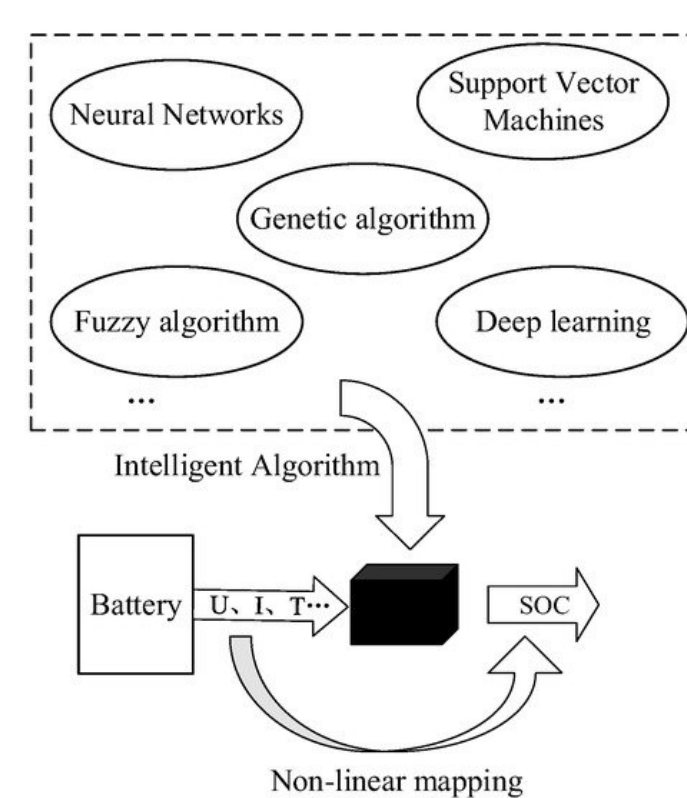
- In black box method, the battery model is considered an unknown system and can estimate SoC without prior knowledge of battery chemistry. The inputs of this model are online measurable battery current, voltage, temperature, and the like, while SoC is considered the output.
- Having access to an accurate model and stochastic properties of the system helps us to benefit from the advantages of the estimators and observers. By using different estimation algorithms and the measurable variable like current, voltage, temperature, and the like, the SoC or other states can be easily estimated.

Proposed 3rd Order SVSF

- The smooth variable structure filter (SVSF) is a model-based robust filter. This filter takes advantage of an inherent switching action to keep the estimation error within an acceptable region.
- Proposed 3rd order SVSF uses more information in compared to the other SVSF based filters leading to better performance.
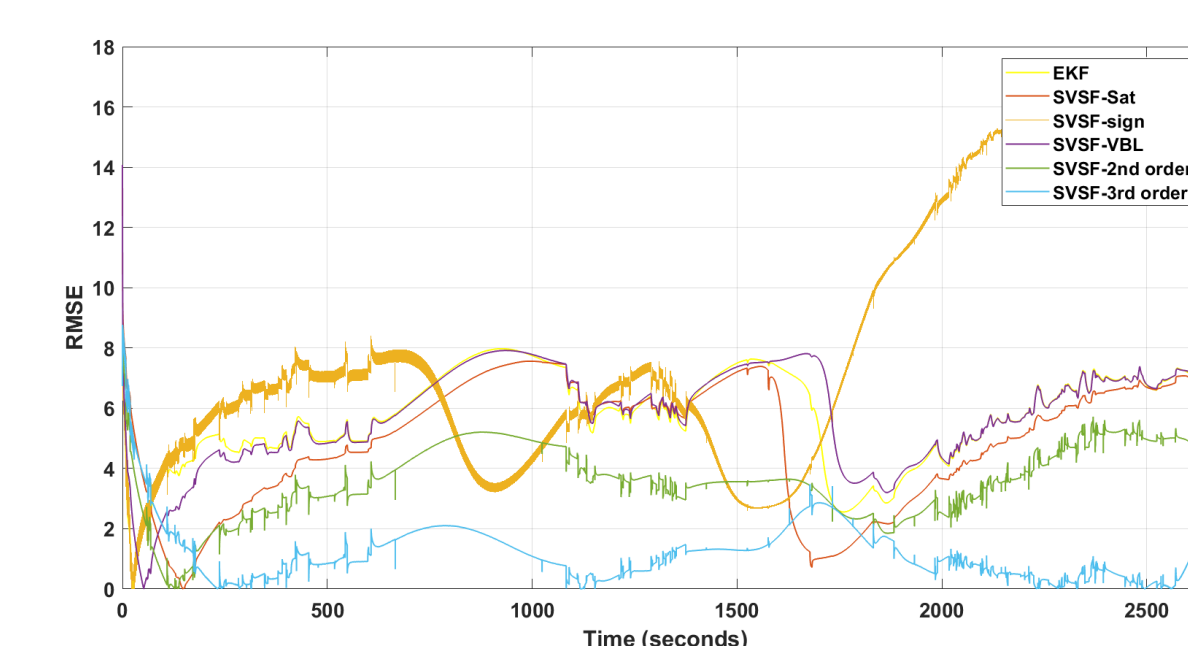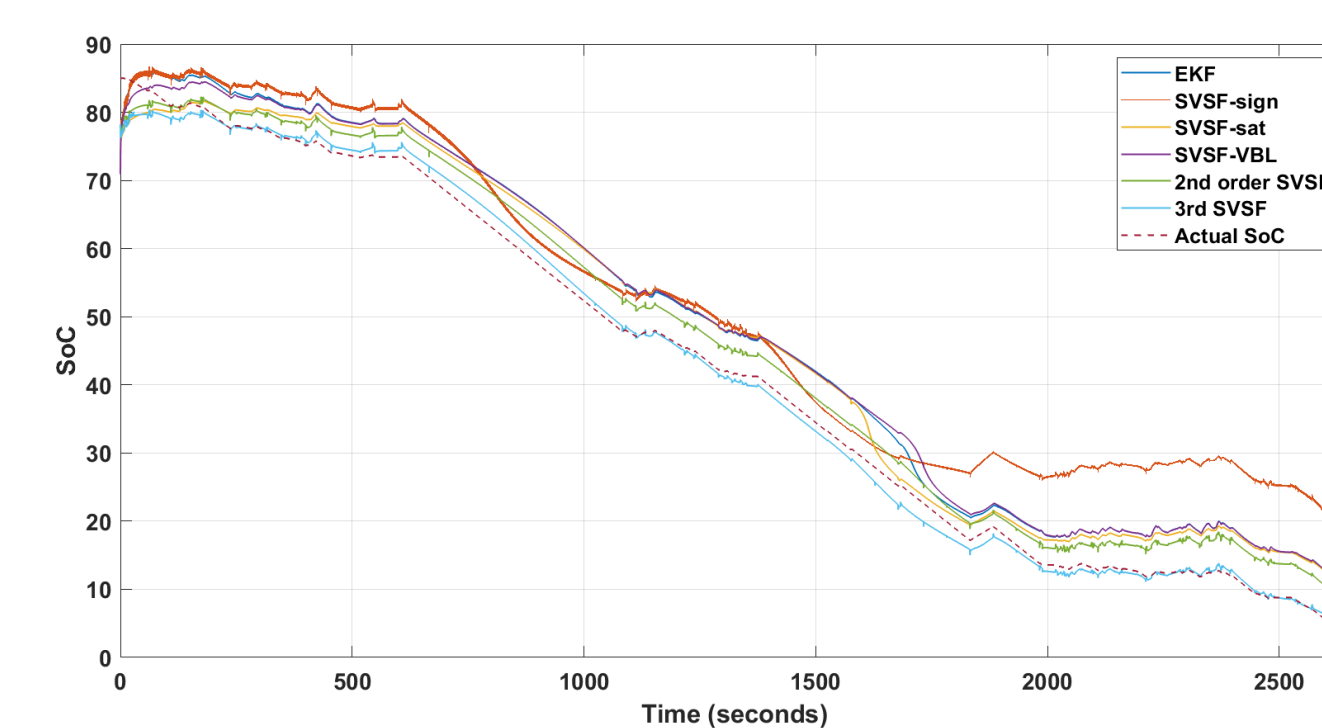- This filter is used to estimate the SoC of the battery using an equivalent circuit model (ECM).

- Prediction Stage:
- The a priori state estimate vector

- $\hat{x}_{k+1|k} = f(\hat{x}_k, u_k)$
- $\hat{z}_{k+1|k} = H\hat{x}_{k+1|k}$
- $e_{z_{k|k}} = z_k - H\hat{x}_{k|k}$
- $e_{z_{k+1|k}} = z_{k+1} - H\hat{x}_{k+1|k}$

- Update Stage:
- Proposed Corrective gain

- $K_{k+1} = H^{-1}\left[e_{z_{k+1|k}} - e_{z_{k|k}} + \frac{e_{z_{k-1|k-1}}}{2} - \right.$

$$\left. \sqrt{\frac{(e_{z_{k-1|k-1}} \circ e_{z_{k-1|k-1}})}{4} - (e_{z_{k|k}} \circ e_{z_{k|k}}) + (e_{z_{k-1|k-1}} \circ e_{z_{k|k}}) + \frac{\gamma^2 (E_{z_{k|k}} \circ E_{z_{k|k}})}{2}} \right]$$


Filters	EKF	SVSF-sat	SVSF-sign	SVSF-VBL	2nd order SVSF	3rd order SVSF
Mean RMSE(%)	5.7418	4.9312	8.3705	5.7851	3.5755	1.1731

- Results clearly show that the proposed 3rd-order SVSF surpasses EKF and SVSF-based filters in terms of accuracy and convergence time.
- This strategy can be used for real-time BMS by using measured voltage, current and temperature, which is facilitated by Speedgoat and data BMS boards.

Battery Pack | Data Collection | Real-Time Battery Management | SpeedGoat
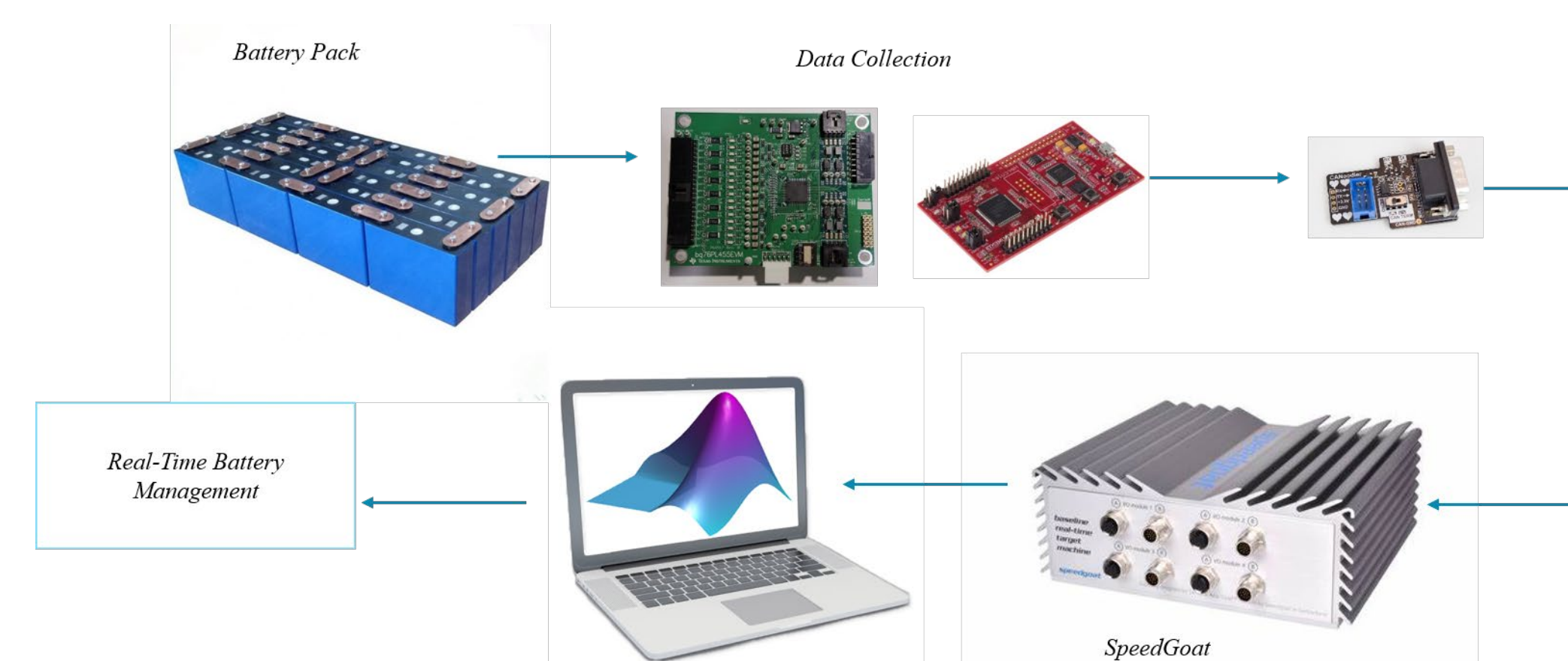
SoT Estimation Flow Chart

- The analysis of battery core temperature is critical for BMS to protect the li-ion batteries from thermal runaway reactions which can lead the batteries to potential damage, but directly it is difficult to measure.
- Since the battery model can be affected by different temperatures, an estimation of core temperature can help us to use a more accurate battery model.
- This approach can be implemented by defining new coefficients for the battery resistors and capacitors in ECM or simply by using lookup tables and different ECM for each.
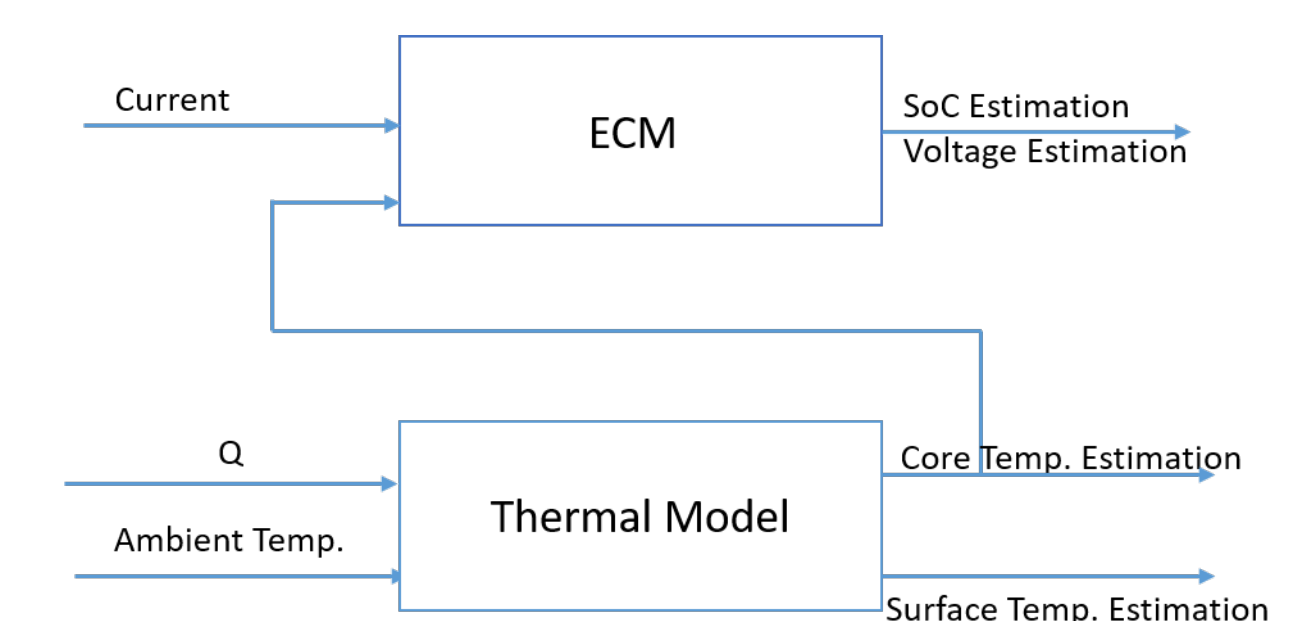
- $C_c \frac{dT_c}{dt} = \dot{Q} + \frac{T_s - T_c}{R_c}$
- $C_s \frac{dT_s}{dt} = \frac{T_{amb} - T_s}{R_u} - \frac{T_s - T_c}{R_c}$
- $\dot{Q} = I(U - V) + I\left(T\frac{\partial U}{\partial T}\right)$

Conclusion and Future Works

- Robust estimation strategy and accurate model are the important issues that should be considered in order to have an accurate estimation. In this study, it is expected that the accuracy will be considerably increased by using the proposed filter with a new algorithm and new Core-temperature-based ECM. Therefore, future research will be focused on:

- Studying observability
- Establishing an adaptive or intelligent model
- Considering IMM and Novel IMM
- SoT estimation
- Studying the joint state estimation
- Developing Advanced estimation algorithms for BMS based on SVSF

References

[1] Habibi, S. (2007). The Smooth Variable Structure Filter. *Proceedings of the IEEE, 95*(5), 1026–1059. https://doi.org/10.1109/JPROC.2007.893255
[2] Afshari, H. H., Attari, M., Ahmed, R., Delbari, A., Habibi, S., & Shoa, T. (2018). Reliable state of charge and state of health estimation using the smooth variable structure filter. *Control Engineering Practice, 77*, 1–14. https://doi.org/10.1016/j.conengprac.2018.04.015
[3] Rahimifard, S., Advanced state estimation for electric vehicle batteries. PhD thesis, McMaster University, 2022.
[4] Ahmed, R., Modeling and state of charge estimation of electric vehicle batteries. PhD thesis, McMaster University, 2014.
[5] Farag, M., Sweity, H., Fleckenstein, M., & Habibi, S. (2017). Combined electrochemical, heat generation, and thermal model for large prismatic lithium-ion batteries in real-time applications. *Journal of Power Sources, 360*, 618–633. https://doi.org/10.1016/j.jpowsour.2017.06.031
[6] Zhou, W., Zheng, Y., Pan, Z., & Lu, Q. (2021). Review on the Battery Model and SOC Estimation Method. *Processes, 9*(9), 1685. https://doi.org/10.3390/pr9091685
[7] Wang, Y., Tian, J., Sun, Z., Wang, L., Xu, R., Li, M., & Chen, Z. (2020). A comprehensive review of battery modeling and state estimation approaches for advanced battery management systems. In *Renewable and Sustainable Energy Reviews* (Vol. 131). Elsevier Ltd. https://doi.org/10.1016/j.rser.2020.110015

McMaster University | University of Windsor | Western | CMHT CENTRE FOR MECHATRONICS AND HYBRID TECHNOLOGIES | Ontario Research Fund | NSERC CRSNG