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

Centre for Mechatronics and Hybrid Technology
Mechanical Engineering-McMaster University
Farzaneh Ebrahimi, Dr. Ryan Ahmed, Dr. Saeid Habibi

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

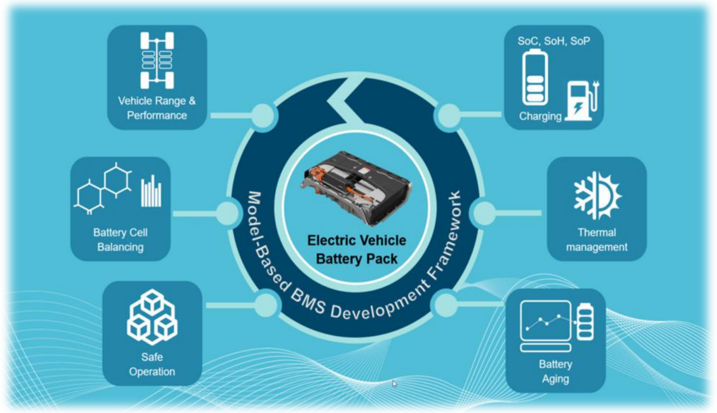


Fig. 1 BMS

- The following block diagram shows how real-time BMS can be facilitated by using Speedgoat_MathWorks and data collection boards.

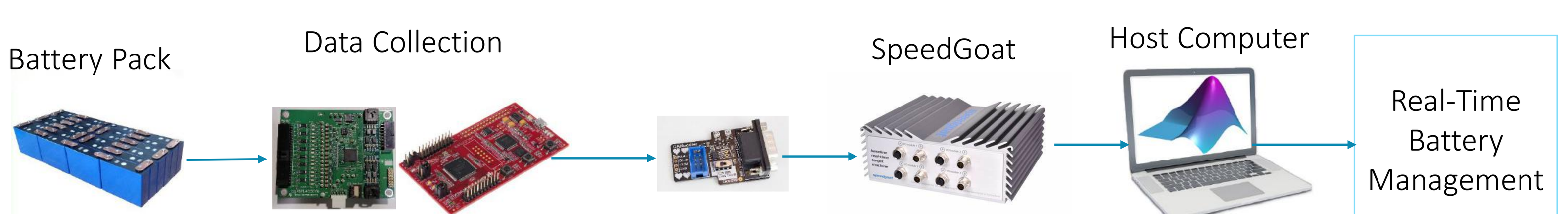


Fig. 2 Experimental Connections

Estimation Strategies

- Considering the fact that the battery model 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
- **SoC estimation method based on the Equivalent Circuit model of the battery**
- 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 measurable variables like current, voltage, temperature, and the like, the SoC or other states can be easily estimated.

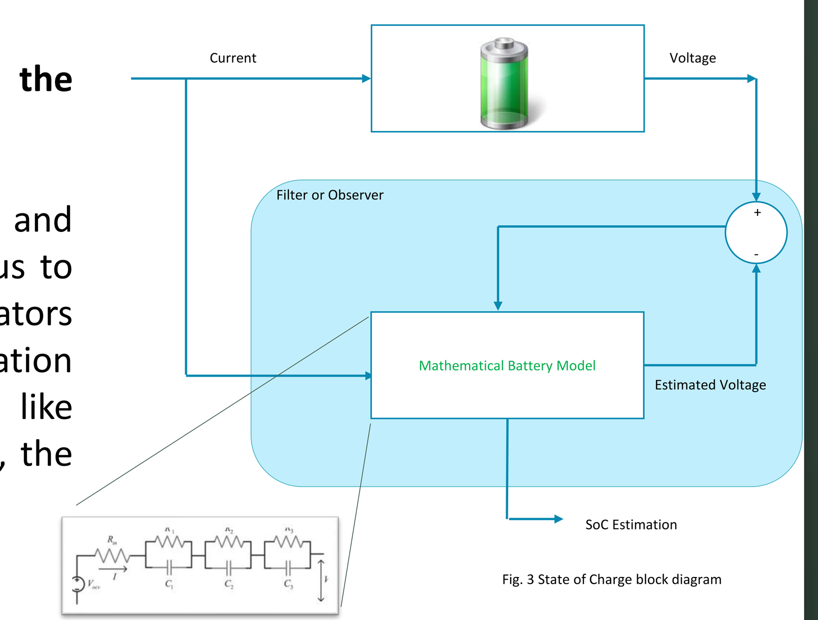
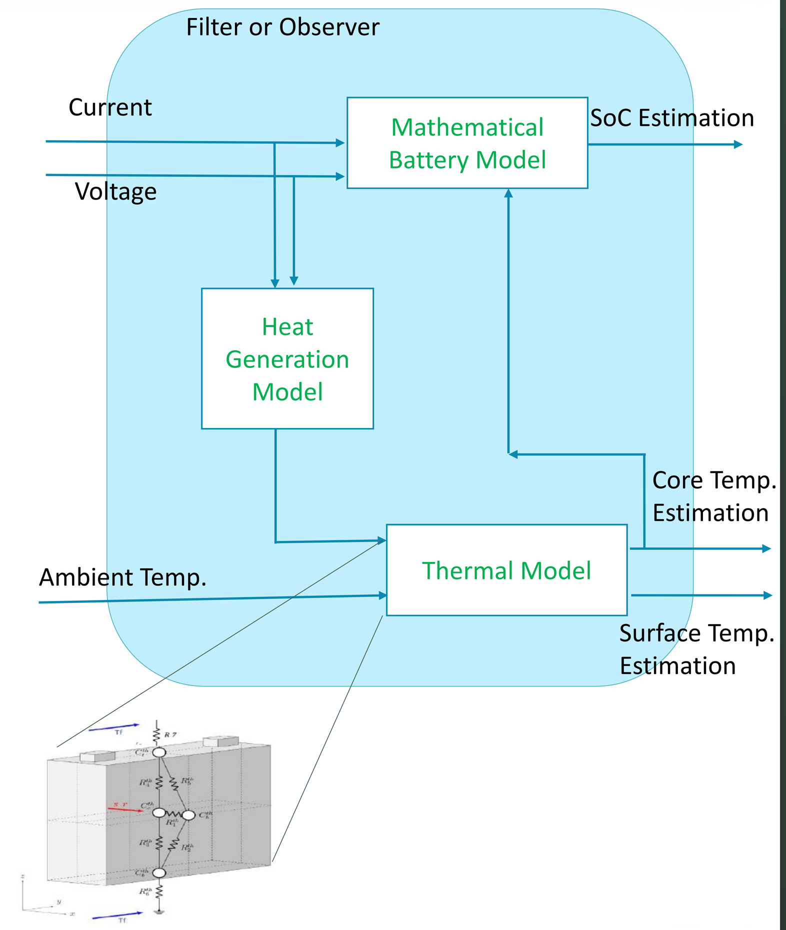


Fig. 3 State of Charge block diagram

State of Temperature (SOT) Estimation

- **SOT estimation method based on the thermal model of the battery**
- The analysis of battery core temperature is critical for BMS to protect the li-ion batteries from thermal runaway reactions which can lead 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.



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 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).

- **3rd Order SVSF Algorithm**
- 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
- $K_{k+1} = H^{-1}\left[e_{z_{k+1|k}} - e_{z_{k|k}} + \frac{e_{z_{k-1|k-1}}}{2} - \sqrt{\frac{\left(e_{z_{k-1|k-1}} \circ e_{z_{k-1|k-1}}\right)}{4} - \left(e_{z_{k|k}} \circ e_{z_{k|k}}\right) + \left(e_{z_{k-1|k-1}} \circ e_{z_{k|k}}\right) + \frac{\gamma^2\left(E_{z_{k|k}} \circ E_{z_{k|k}}\right)}{2}}\right]$

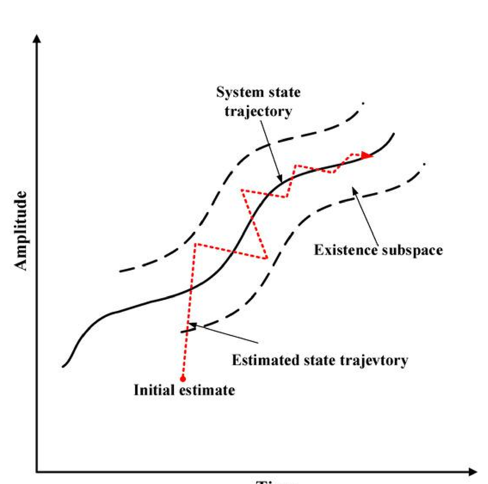
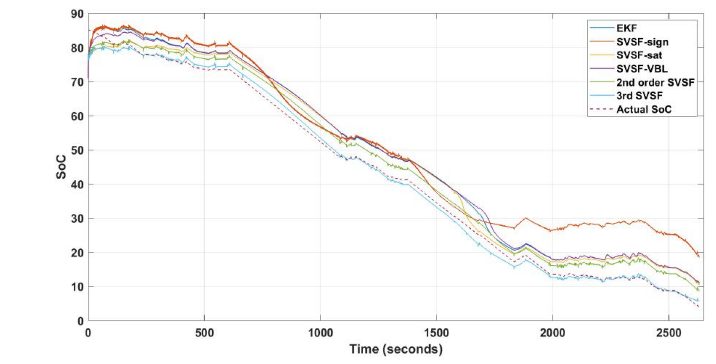
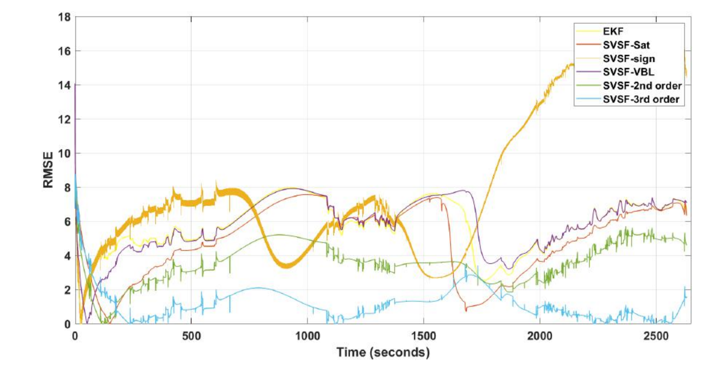


Fig. 5 Concept of Smooth Variable Structure Filter

Simulation Results

- Results clearly show that the proposed 3rd-order SVSF surpasses EKF and other SVSF-based filters in terms of accuracy by 60%.
- Also, it is shown that the proposed filter converges faster than the aforementioned filter.





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

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
[8]Chengdu: battery management system lab to reduce testing – Simcenter, https://blogs.sw.siemens.com/simcenter/chengdu-battery-management-system-lab-to-reduce-testing, Accessed: 2023-04-20
[9] EV not that EZ, https://www.trianguluumedia.com/ev-not-that-ez, Accessed: 2023-04-20
[10] Speedgoat - System Integration Services - Real-time simulation and testing with Simulink - Third-Party Products & Services - MATLAB & Simulink, https://www.mathworks.com/products/connections/product_detail/speedgoat-system-integration.html, Accessed: 2023-04-20

McMaster University | University of Windsor | Western | CMHT Centre for Mechatronics and Hybrid Technologies | Ontario Research Fund | NSERC CRSNG

We acknowledge the support of the Ontario Research Fund: Research Excellence Program.

We acknowledge the support of the Natural Sciences and Engineering Council of Canada (NSERC), which invests annually over $1 billion in people, discovery and innovation.