Fault Detection for Lithium-Ion Battery Using SVSF
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**What and Why**
- A battery management system (BMS) is an embedded system which is utilized to ensure safe and effective control of lithium-ion cells and modules in a battery pack, including the State of Charge (SOC) and the State of Health (SOH) estimation.
- The main sensors outputs of the BMS are voltage, current.
- Sensor faults are external fault.
- They cause BMS failure in SOC, SOH, and Voltage estimations leading to overcharge or discharge of the pack.
- Predefined faults in current and voltage sensors are simulated and applied to a battery model. The model is estimated separately by SVSF and SVSF-VBL to evaluate these estimators' fault detection and isolation performance compared to EKF.
- CUSUM algorithm is used in the evaluation phase of the residuals.

**Filters**
- EKF is a non-linear predictor-corrector estimator applying linearization by using a Taylor Series expansion with 1st order terms.
- SVSF is a non-linear robust filter, that has a predictor-corrector form, its gain formulation is based on the sliding mode theory.
- SVSF-VBL uses the state error covariance matrix of the SVSF to derive an optimal time-varying smoothing boundary layer.

**Residual evaluation**
- Residual evaluation helps to extract fault occurrences which are directly undetectable from residuals
- The CUSUM provides a binary hypothesis space analyzing which of the two possible hypotheses \( \theta_0 \) (non-faulty) or \( \theta_1 \) (faulty) is true based on information received from the estimator residual at each time frame, by calculating the log-likelihood ratio between probability functions of these hypotheses.
- A recursive signal \( g(t) \) is developed based on the cumulative sum of the log-likelihood ratio it replaces any probable negative growth in the boundary layer width.
- This indicates that SVSF-VBL has a higher capability to detect smaller faults compared to EKF and SVSF.
- The graphs below show the decision signal and the require threshold for four different faults with three filters used.

**Results**
- The graphs below show the decision signal and the require threshold for four different faults with three filters used.

**Comparison**
- The table summarizes the threshold values, the detectability and detection delays for the three filters in the presence of four different faults.

<table>
<thead>
<tr>
<th>Fault</th>
<th>EKF</th>
<th>SVSF</th>
<th>SVSF-VBL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault 1: A current sensor fault with 20% off scaling at a time interval between ( T = 14000s ) and ( T = 16000s )</td>
<td>( J = 8500 )</td>
<td>( J = 68 )</td>
<td>( J = 18000 )</td>
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<tr>
<td>Fault 2: 3.7 V sticking voltage sensor fault at a time interval between ( T = 16000s ) and ( T = 18000s )</td>
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<tr>
<td>Fault 3: −0.2V bias voltage sensor fault at a time interval between ( T = 16000s ) and ( T = 18000s )</td>
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<td>Fault 4: N/A</td>
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</table>
- For other faults, EKF and SVSF-VBL have almost the same detection time.
- This indicates that SVSF-VBL has a higher capability to detect smaller faults compared to EKF and SVSF.
- EKF shows superior performance with significantly lower detection delay for fault 4.

**Conclusion & Future Work**
- The study investigates Smooth Variable Structure Filter (SVSF)-based methods for battery cell fault detection with a focus on sensor failures that interfere with the measurement of current and voltage of batteries.
- SVSF-based filters were utilized to calculate the battery Charge (SoC) and terminal voltage.
- The proposed method shows effectiveness in fault detection, with a lower required threshold than that of the Extended Kalman Filter (EKF) and a similar detection delay for most faults.
- The Cumulative Sum (CUSUM) technique increased the accuracy of fault detection, particularly for sticky voltage issues.
- The study can help develop better fault-detection strategies for batteries, which can prevent system failures and ensure safe and reliable operation.

**References**
Complete reference list is available at: https://github.com/Rezahnd/Fault-Detection-Project/blob/main/References.md