Genetic Algorithm Based Charge Optimization of Lithium-Ion Batteries in Small Satellites

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Outline

• Problem Identification
• Solution approaches
• Our strategy
  – Problem representation
  – Modified Genetic algorithm
• Results
• Conclusion and Future work
Problem Identification

How to autonomously optimize the battery state of charge while meeting the diverse requirements of all the subsystems and payloads?
Solution Approaches

• Increase the solar array size or battery size
• Have a pre-decided time multiplexed operation sequence
  – Needs a highly skilled team - time, cost
  – Reduced capability to react to unforeseen events
  – Needs frequent updates from ground station
Our Strategy

Scheduling of operations of the spacecraft

• Achieve optimum charge levels in the batteries while ensuring uninterrupted operation

• Enhance battery life so that the mission life can be extended
Our Strategy

Presence of an autonomous agent for scheduling operations

• Decides the best sequence of operations given a set of tasks
• It can be interrupted if needed or overwritten
• The sequences are generated so that the power utilization is optimum, and battery life is not compromised
Problem Representation

- The distribution system consists of load nodes
  - Nodes = power sinks
  - Nodes have power ratings
  - Nodes can be composite units
- A ‘star’ topology of the distribution system
Problem Representation

- There is a set of tasks to be completed
- Each task consists of a sequence of operations
- Every operation has associated constraints
- Operation sequences are non-repetitive
- To perform an operation is to activate/power up the associated node
- At any instant an operation can be associated with only one task
- Multiple tasks can have the same operation at different times
Problem Representation

- Multiple tasks can be scheduled in parallel
- Some or all of the operations of the active tasks can be scheduled at the same time
Genetic Algorithm

• Genetic Algorithm (GA) is an optimization method based on the mechanics of natural selection
• Good for multi-objective optimization problems
• Operates on a population of possible solutions, enhances them in successive iterations (generations) while converging towards the optimum
Modified Genetic Algorithm

- A rule base is evolved and optimized by the GA
- The rule base is then decoded to the actual schedule by a decoder
- Fixed number of GA iterations are done to generate a schedule
- Schedule processing, i.e. the operations activate the corresponding nodes
Modified Genetic Algorithm

- Different fitness functions are used for day and night
- Daytime - to achieve maximum charge and the tasks completion in minimum time
- Eclipse - to achieve minimum depth of Li-Ion battery discharge while not interrupting any other operation
Results - Matlab

Mean Fitness (slack) vs. Iteration for Eclipse Period

Charge remaining in the battery after all the operations are completed

POP = 20
GEN = 30
Pc = probability of crossover
Results – Matlab

Mean Cost (time) vs. Iteration for Daylight Period

Time to complete all the tasks (mean flow time)

POP = 40
GEN = 20
TIME = 92 min
Results - FPGA/VHDL

- Implementation using single precision arithmetic
- Total duration of scheduling is 20 min
- Evaluation frequency is 3.9 KHz

<table>
<thead>
<tr>
<th></th>
<th>Actual VHDL Output</th>
<th>Theoretical Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>148.41</td>
<td>148.14</td>
</tr>
<tr>
<td>Time</td>
<td>89.09</td>
<td>89.09</td>
</tr>
<tr>
<td>Charge</td>
<td>2555.62</td>
<td>2555.70</td>
</tr>
</tbody>
</table>
Conclusions and Future Work

- The optimizer has achieved satisfactory performance
- Better tuning and longer runs of the GA can result in better solutions
- A complete hardware system test needs to be done
- Simplification of the cost function for discharging can be done by using methods like Kalman Filters
- Other satellite based applications of GAs can be
  - control algorithm tuning
  - mission planning
  - physical layout optimization
  - test plan generation
Questions
Questions
Backup Slides
# Mathematical Definitions

## Mathematical Definition of the Priority Rules Used

<table>
<thead>
<tr>
<th>Priority rule</th>
<th>Description</th>
<th>Formula</th>
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</thead>
<tbody>
<tr>
<td>SPT</td>
<td>shortest processing time</td>
<td>( \min d_i )</td>
</tr>
<tr>
<td>LFT</td>
<td>latest finish time</td>
<td>( \min LFT_i )</td>
</tr>
<tr>
<td>LST</td>
<td>latest start time</td>
<td>( \min LFT_i - d_i )</td>
</tr>
<tr>
<td>MST</td>
<td>most total successors</td>
<td>( \max</td>
</tr>
<tr>
<td>MSLK</td>
<td>minimum slack</td>
<td>( \min (due_time - current_time - remaining_time) )</td>
</tr>
<tr>
<td>WRUP</td>
<td>weighted resource utilization and precedence</td>
<td>( \max 0.7</td>
</tr>
<tr>
<td>FCF</td>
<td>first come first</td>
<td>First element of ( S_\phi )</td>
</tr>
</tbody>
</table>
Li-Ion Equations

\[
\sigma = \sum_{k=0}^{n-1} I_k \left[ \Delta_k + 2 \sum_{m=1}^{\infty} \frac{e^{-\beta^2 m^2 (T-t_k-\Delta_k)} - e^{-\beta^2 m^2 (T-t_k)}}{\beta^2 m^2} \right]
\]

\((\kappa = \alpha - \sigma)\)

\[
\langle F \rangle = \frac{1}{J} \sum_{i=1}^{J} C_i - R_i
\]