Improving the Quality of Supervised Finite-State Machine Construction Using Real-Valued Variables

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Problem Statement

Finite-State Machine:
- FSM = (S, δ, E, A, δ, λ)
- S – finite set of states
- S0 – initial state
- E, A – event and action sets
- δ: S × E → S – transition function
- λ: S × E → A – output function

Problem:
- Real-valued inputs and outputs
- Tests (N = 20–30) are the examples of proper control
- Construct an FSM with behavior close to the tests
- Aircraft model is used as a controlled object
- Tests can be written manually in a flight simulator
- Test example:

<table>
<thead>
<tr>
<th>Values</th>
<th>Description</th>
<th>t = 1</th>
<th>...</th>
<th>t = 10</th>
<th>...</th>
<th>t = 235</th>
</tr>
</thead>
<tbody>
<tr>
<td>in[t, l1]</td>
<td>Pitch angle (°)</td>
<td>3.078</td>
<td>...</td>
<td>3.544</td>
<td>...</td>
<td>4.112</td>
</tr>
<tr>
<td>in[t, l2]</td>
<td>Airspeed (knots)</td>
<td>251.42</td>
<td>...</td>
<td>252.29</td>
<td>...</td>
<td>253.20</td>
</tr>
<tr>
<td>out[t, l1]</td>
<td>ailer position</td>
<td>0.000</td>
<td>...</td>
<td>0.032</td>
<td>...</td>
<td>0.073</td>
</tr>
<tr>
<td>out[t, l2]</td>
<td>Elevator position</td>
<td>-0.035</td>
<td>...</td>
<td>-0.039</td>
<td>...</td>
<td>-0.037</td>
</tr>
</tbody>
</table>

FSM Learning

- Methodology:
  - Record tests
  - Learn FSMs
  - Examine FSMs in simulation
- ACO-based algorithm
- FSMs with undefined output functions are individuals
- Output actions are derived so that the fitness function is maximized
- Fitness function:
  \[ f = 1 - \frac{1}{N} \sum_{i=1}^{N} \rho^2(\text{ans}[i], \text{out}[i]) - K \left( \frac{1}{N} \sum_{i=1}^{N} (\max(\tau_i - |S| + 1, 0))^2 \right) \]
  \[ \rho(\text{ans}[i], \text{out}[i]) = \frac{1}{\text{len}[i]} \sum_{i=1}^{\text{len}[i]} \sum_{j=1}^{C} \left( \text{ans}[i, j] - \text{out}[i, j] \right)^2 \]
  - C – number of outputs
  - ans[i] – FSM’s output for the i-th test
  - τi – number of state changes on the i-th test

Experiments & Results

- Quad-core Intel Core i7–2670QM processor
- 3 test sets, number |S| of states: 3..5
- Method execution time: about 10 minutes
- Comparison with the previous representation
- Fitness values:

<table>
<thead>
<tr>
<th></th>
<th>FSM Representation</th>
<th>Loop</th>
<th>Barrel roll</th>
<th>Turn</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Proposed</td>
<td>0.9856</td>
<td>0.9854</td>
<td>0.9892</td>
</tr>
<tr>
<td></td>
<td>Previous</td>
<td>0.9812</td>
<td>0.9832</td>
<td>0.9842</td>
</tr>
<tr>
<td>4</td>
<td>Proposed</td>
<td>0.9866</td>
<td>0.9863</td>
<td>0.9898</td>
</tr>
<tr>
<td></td>
<td>Previous</td>
<td>0.9836</td>
<td>0.9856</td>
<td>0.9901</td>
</tr>
<tr>
<td>5</td>
<td>Proposed</td>
<td>0.9873</td>
<td>0.9868</td>
<td>0.9901</td>
</tr>
<tr>
<td></td>
<td>Previous</td>
<td>0.9842</td>
<td>0.9858</td>
<td>0.9902</td>
</tr>
</tbody>
</table>

- Quality is improved
- Now it is possible to construct FSMs performing the turn

Publications


Screenshots (FlightGear simulator)

- Loop
- Turn

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