Model-driven Performance Analysis of Reconfigurable Conveyor Systems used in Material Handling Applications

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Presentation Roadmap

- Motivation
  - Conveyor systems
  - Why Reconfigurable Conveyors?
  - Challenges and Solution
Conveyor Systems

- Traditional Conveyor Systems (UPS, FedEx)
- Reconfigurable Conveyor Systems (DynaCon)
Why Reconfigurable Conveyors?

- Flexibility
- Scalability (Sustainability)
- Cost Effective
Basic Elements of Reconfigurable Conveyors

- **Segments**

- **Turnarounds**
Example of Reconfigurable Conveyors
Challenges

- Frequent changes in product lines
- With changes in layouts, how do we answer these questions?
  - Maximum sustainable rate?
  - Starvation of certain paths?
  - Inter material spacing?
  - Prioritization?
  - Fault tolerance?
Solution

- Model-driven Performance Analysis
  - Analysis engine
  - Domain-specific modeling language
  - Automation through generative capabilities
Presentation Roadmap

- Motivation
  - Conveyor systems
  - Why Reconfigurable Conveyors?
  - Challenges and Solution

- Design of Framework
  - Overview of Architecture
  - Metamodel, DSML, and Generative Capabilities
  - Analysis Engine: Cyber and Physical Models
Overview of Architecture

- Design-time performance analysis framework
- GME based structural models
- MATLAB Simulink based behavior models

Diagram:

- Generic Modeling Language (GME)
  - Conveyor Systems Meta-model
    - Instance of
      - Conveyor Systems Domain-specific Model
        - Interpreter of
          - Conveyor Systems Matlab Simulink Testbed Code Generator

- Matlab Simulink Analysis Testbed
  - Conveyor Systems Cyber Model
    - Transfer State Machine
    - Receiver State Machine
  - Instrumentation Interface
    - Conveyor Systems Physical Model
      - Belt Control Data
      - Physical Sensor Data
Meta-model and Domain-specific Model

- **Meta-model**
  - Heart of the Domain-specific Modeling Language

- **Domain-specific Model**
  - High level of abstraction of the system
  - Configures attributes for the building blocks
  - Allows analysts to create topologies
  - Transforms into the underlying artifacts
Generative Capabilities

DSML → GME Interpreter → MATLAB Script → MATLAB Simulink → Analysis Results
Analysis Engine

- Cyber Models
  - Logical controllers implemented by Simulink Stateflow

- Physical Models
  - Physical behaviors implemented by Simulink blocks

- Conveyor Skids
  - Modularized units
  - Self-contained unit representing both cyber and physical elements
Analysis Engine: Cyber Models

Segment Transfer FSM

- Start Comm WD
- Send "request"
- Wait 'response'
- Decrease Part
- Stop Conveyor
- "Comm WD" expires
- "TX WD" expires or done
- "Sd" inactive and num_parts > 0
- "Sd" active and num_parts > 0
- Wait "done"
- Start "TX WD"
- Wait Transfer
- Start Conveyor

Turnaround Receiver FSM

- Receive "request" and "Sr" inactive and has_part == 0
- Start RX WD
- Send "response"
- Wait Until Center
- Increase Part
- Decide Route
- Start RX RD expires
- Stop Conveyor
- Wait Part Receive
- "Sr" active
Analysis Engine: Cyber Models

Turnaround Transfer FSM

Segment Receiver FSM
Analysis Engine: Physical Models

- Physical models in the analysis engine
- Abstract view of Segment

Diagram:
- Input Package Pulse
- Belt Speed
- Upstream Sensor
- Downstream Sensor
- Su and Sd

Box:
- Belt Statistics Calculator
- Package Data Store
- Package Release Controller
- Upstream and Downstream Sensor Controllers
- Receiver Counter
- Transfer Counter
Physical models in the analysis engine

Abstract view of Turnaround
Presentation Roadmap

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- Experimental Results
Experimental Results

- Example reconfigurable conveyor system

<table>
<thead>
<tr>
<th>Package Type</th>
<th>Length of Package</th>
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<tbody>
<tr>
<td>Small Package</td>
<td>1m</td>
</tr>
<tr>
<td>Medium Package</td>
<td>1.5m</td>
</tr>
<tr>
<td>Large Package</td>
<td>2m</td>
</tr>
</tbody>
</table>

**Experiment Parameters**

<table>
<thead>
<tr>
<th>Block Type</th>
<th>Belt Velocity</th>
<th>Belt Length</th>
<th>Sensor Zone</th>
<th>RX WD</th>
<th>TX WD</th>
<th>COMM WD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment</td>
<td>1 m/s</td>
<td>20 m</td>
<td>2 m</td>
<td>10 secs</td>
<td>10 secs</td>
<td>0.5 secs</td>
</tr>
<tr>
<td>Turnaround</td>
<td>1 m/s</td>
<td>5 m</td>
<td>1 m</td>
<td>10 secs</td>
<td>10 secs</td>
<td>0.5 secs</td>
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</tbody>
</table>
Experimental Results

- Experiment 1

**Sustained Input Rates of Packages**

**Observed Output Rates of Packages**
## Experimental Results

### Experiment 2

<table>
<thead>
<tr>
<th>COMM_WD</th>
<th>Small Packages Arrived</th>
<th>Medium Packages Arrived</th>
<th>Large Packages Arrived</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5sec</td>
<td>94</td>
<td>94</td>
<td>78</td>
</tr>
<tr>
<td>0.1sec</td>
<td>102</td>
<td>79</td>
<td>62</td>
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</table>

### Number of Packages Arrived for Different COMM_WD Timer Values

![Comparing the Total Numbers of Packages Arrived](image)
Concluding Remarks and Future work

- Model-driven analysis framework for reconfigurable conveyor systems
  - Decouples structural models from behavior models
  - Evaluates the properties of the topology proposed
  - Automation through generative capabilities

Future work

- Fault-tolerant reconfigurable conveyor systems
- Prioritizing packages according to types
- General framework of reconfigurable conveyor systems through commonality and variability analysis
Question?