Interconnection of the behavior-based control architecture and a detailed machine model for realistic behavior verification of the THOR project

Daniel Schmidt
Robotics Research Lab
Department of Computer Science
University of Kaiserslautern
September 16, 2013
THOR (Terraforming Heavy Outdoor Robot)

Volvo EW/180B

- Mass: 18t
- Lifting force $\approx 100$kN

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>2.92 m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>8.72 m</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3.17 m</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>1.29 m</td>
</tr>
</tbody>
</table>
Excavator extensions

- Electronic control valves
- Laser scanners
- Boom joint sensors (elongation)
- Controller boards
- Personal Computer
Long-term project objective

“Develop a fully autonomous mobile excavator”

Typical operations
- Move material from a to b
- Reshape the surface (+/-)
- Continuously load trucks
- Locate & reposition on site

Spin-off results for the human operator

Assistance systems improving efficiency and safety
Global scenario

Problem:

Actual Surface

?  Desired Surface
Development steps

1. Environment simulation (safe tests)
   - Simulated excavator
   - Obstacles (buildings, infrastructure . . .)

2. Perception algorithms
   - Classification of surface(s) and objects
   - Detection of changes

3. Autonomous control structure
   - Identify next excavation position
   - Perform complete shaping of the surface
Excavator model

- Visualization: SimVis3D
- Realism: Newton physics
Simulation videos

(the video is a screen-capture and in original speed)
Soil simulation videos

Simulation on GPU via OpenCL

External visualisation (OpenGL)

Excavator simulation (SimVis3D)

(all videos are screen-captures and in original original speed)
Motivation

“The real machine can seriously harm human beings and structures, but a well adjusted parameter set prevents from undesired behavior of the machine”

⇒ A realistic simulation behavior tremendously increases the transferability of the gathered test parameters

⇒ Create a realistic model of the machine and connect it to the existing simulation
Virtual Numeric Control ENvironment - VINCENT

- Importing of STEP geometries
- Import density and mass properties
- Structural view
- Bodies and joints are created and linked manually
- Concept of the virtual commissioning
  - real control + virtual machine
Semi-automated modeling workflow

- Automatic construction of the dynamic boom-model
Modeling of the machine

- Real-time requirements (SW-in-the-loop)
- Fraunhofer IFF “CAD2SIM” approach
  - Automatic generation of the mechanical model from the information given by VINCENT
  - Support of kinematic loops
  - Interface to the hydraulics cylinder model
A single cylinder

- Components of the mechanics, hydraulics, and closed-loop control in one unit.
  - Bidirectional couplings via differential equations
- Losses about internal and external leakages and Strubeck-friction model
- Closed-loop control of the piston
  - Controlled via a proportional valve
Complete hydraulic system

1: Torso
2: Boom
3: Dipper
4: Stick
5: BucketPitch
6: BucketRoll

Daniel Schmidt
Interconnection of iB2C and a detailed machine model
rrlab.cs.uni-kl.de
Data Exchange platform: Real Time Interface (RTI)

- Asynchronous data exchange via distributed shared memory
Autonomous Excavator: control approach

Requirements

- Compute collision free trajectories (static environment)
- Adapt to new detected (dynamic) obstacles/objects
- Perform safe movements (no tilting)
- Run efficient trajectories

⇒ Use the adaptive behaviour-based control approach (iB2C)
Behaviour-based control structure iB2C [Proetzsch09]

- stimulation $s$
- inhibition $\vec{i}$
- activity $\vec{a}$
- target rating $r$
- input vector $\vec{e}$
- output vector $\vec{u}$

- Maximum fusion
- Weighted fusion
- …
5 main behaviours perform surface shaping

- Initial scanning (surface scan)
- Approach position (excavation or dump position)
- Excavate
- Dump

Behaviour-based control cycle

Start

Initial Scanning

Evaluate scan data

Approach excavation position

Approach dumping position

Dump

Excavate

pos found

dumped

started

pos reached

excavated

finished
Example: excavation group

![Diagram of excavation group with nodes and edges representing stimulation, activity transfer, and target rating.]

- **Stimulation**
- **Activity transfer**
- **Target rating**

---

**Figure: Initial Scan**

Daniel Schmidt

Interconnection of iB2C and a detailed machine model

rrlab.cs.uni-kl.de 20
Project results

Simulation

1. Test environment including physical behavior
2. Excavation of soil particles is possible

Real excavator

1. Arm joints, outriggers, shield and drive are controllable
2. Direct and inverse kinematics implemented (drive & boom)
3. Running of teached-in trajectories
4. Behaviour-based control produces suitable trajectories
Operation videos

Simulated bucket excavator

Real excavator loading a truck

“All videos in normal speed - no time adjustment.”
Thanks for your attention!

Any questions?