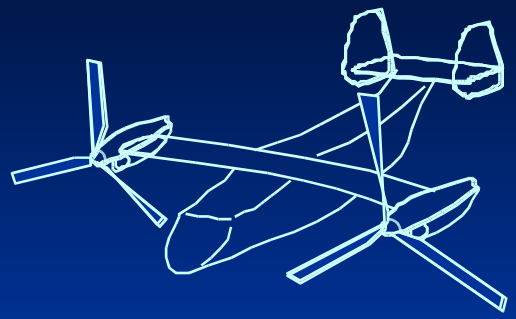

MultiBody Dynamics Analysis Software on Real Time Distributed Systems

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One-day meeting on:
RTAI, present and future
July 8th, 2004

Outline

- Objectives and approach:
  - problem description & requirements
  - software requirements
- Key results:
  - software development
  - model rationalization
  - software performances improvement
- Concluding remarks

Objective

- Develop a *General Purpose Real-Time* experiment simulator:
  - hard real-time capabilities
  - minimal modeling limitations
  - commonality of modeling
- Develop real-time models and controls for a wide spectrum of applications
  - model accuracy
  - analysis accuracy
  - distributed control

Real-Time Simulation

- Requirements:
  - exploit OS multitask/memory protection paradigms
  - use generic libraries (algebra, communication, ...)
  - use general purpose simulation software
  - use/develop Open-Source software
  - run on ''low'' cost platforms (dual Athlon)

Real-Time Simulation

- Proposed solution:
  - RTAI (Real-Time Application Interface) for Linux
    http://www.rtai.org/
  - RTnet (Hard Real-Time Networking for Linux/RTAI)
    http://www.rts.uni-hannover.de/rtnet/
  - MBDyn (MultiBody Dynamics)
    http://www.mbdyn.org/
  - RTAILab data acquisition/control code generation
    http://www.rtai.org/

Real-Time Sim.: Status

- Real-time software:
  - Linux/RTAI mature (industry level applications)
  - simulation software real-time enabled
- Multibody software development:
  - MBDyn multibody mature, multidisciplinary
  - development lines drawn, partially investigated
- Multibody model of COMAU SMART robot:
  - redundant coordinate set model (>100 unknowns)
  - dynamic friction models
  - timings estimates available (up to 2KHz on Athlon 2.4 Ghz equivalent)
  - distributed control via RTAILab/RTnet

Real-Time Simulation

Traditional real-time simulations:

- minimal set (ODE)
- explicit integration
- specialized topology
- bound to OS internals

- fast, fast, fast!
- difficult to extend
- code/tool duplication

Proposed real-time solution:

- redundant set (DAE)
- implicit integration
- general topology
- POSIX compliant

- performance limitations
- code/tool commonality
- modeling flexibility

Real-Time Enabled Software

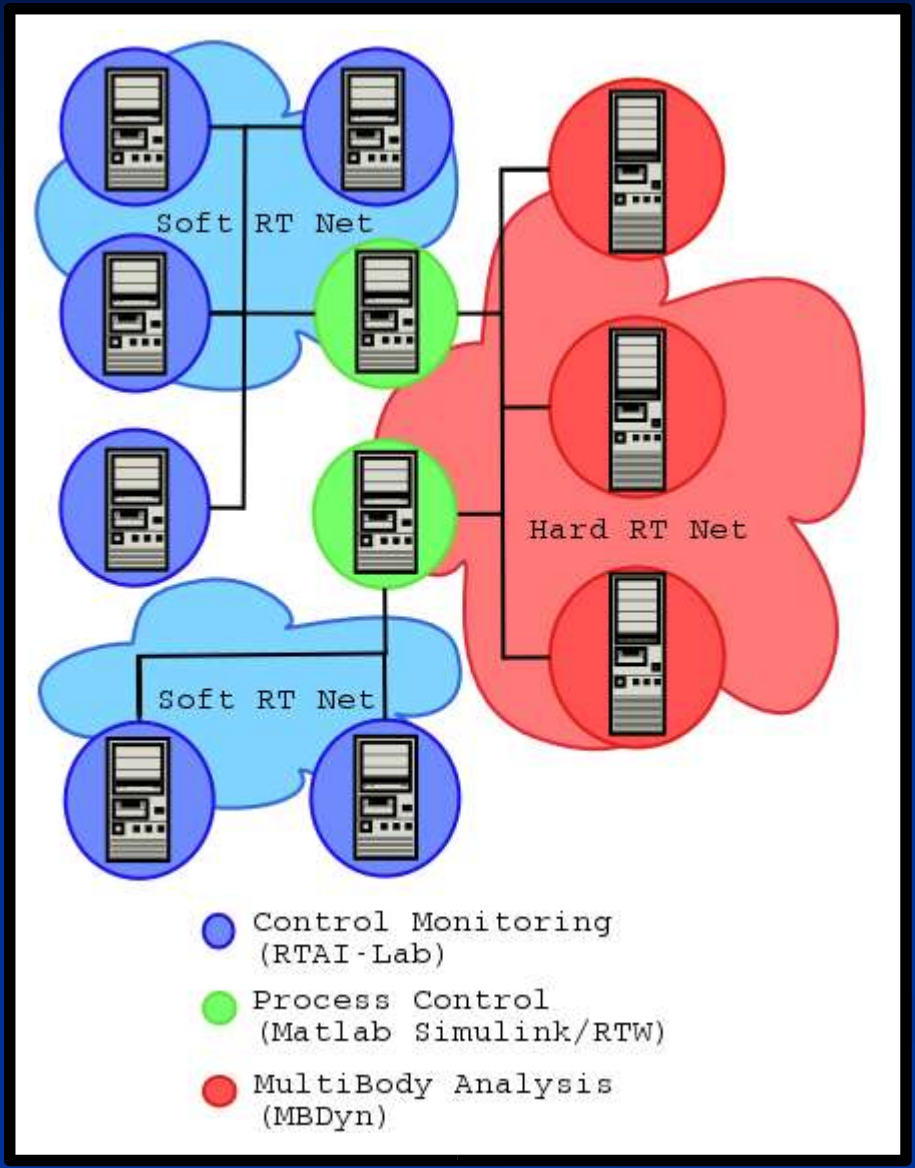
Conventional simulation software

~180,000 LOC

- Avoid / wrap system calls
- Statically preserve stack / initialize resources
- STL containers: memory pools
- Insert few task execution / control statements
- Add real-time I/O communication provisions

Real-time enabled simulation software

Real-Time Enabled Software



- Distributed Real-time software:
  - hard RTnet for control loop
  - soft RTnet for monitoring

MBDyn: Features

- Dynamic analysis of deformable multibody mechanical systems
- Integrated analysis of hydraulic, electric and generic, control related components
- Aeroelastic, rotorcraft-oriented analysis
- Open-Source http://www.mbdyn.org/

MBDyn: Analysis Description

- Dynamics analysis: solution of Initial Value problems (IVP)
- Static/kinematic analysis modeled as downgraded dynamics analysis
- Eigenanalysis by Proper Orthogonal Decomposition of time series

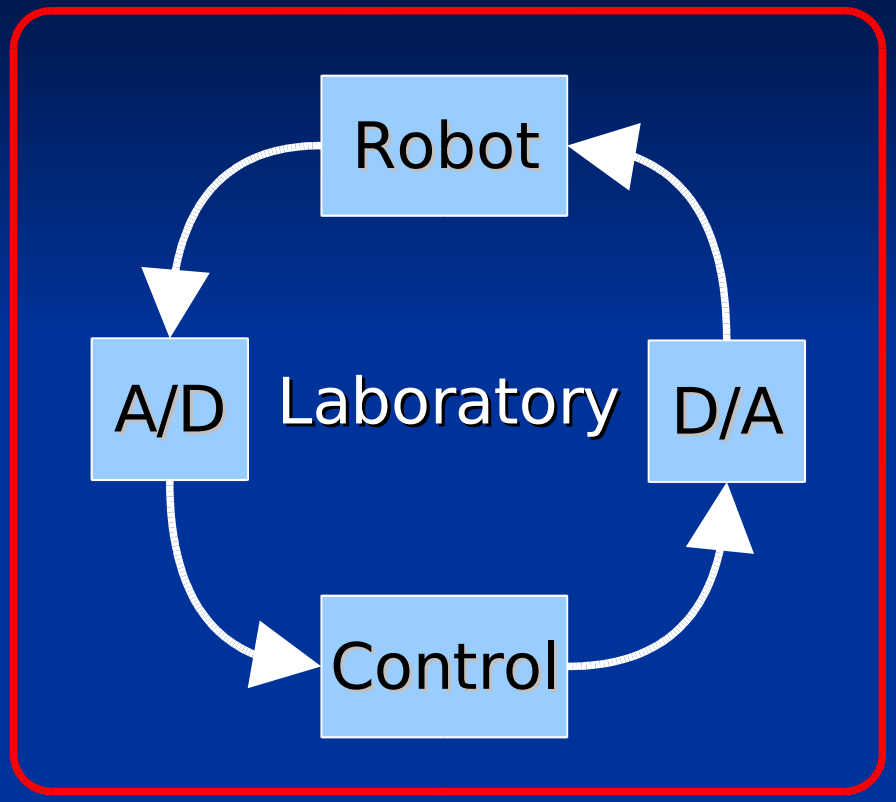
- Typical analysis procedure consists in performing ''virtual experiments''

MBDyn: Analysis Description

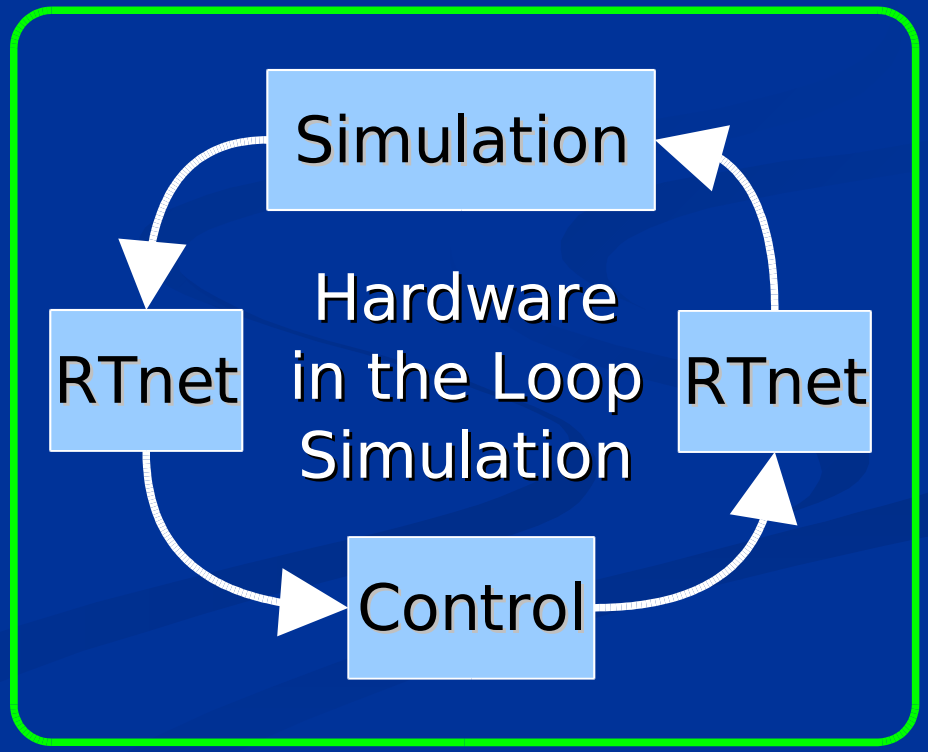
Libraries:

- Mechanical
  - Bodies
  - Joints
    - Rigid
    - Deformable
      - Lumped
      - Beams
      - Modal
  - Absolute/relative position, orientation, vel., acc.
  - Nonlinearities: geometry, contacts, tires, friction
  - Interaction with deformable bodies
- Aerodynamic
  - Rigid/deformable blade element
  - Rotor inflow
  - State-space on modal bodies
  - CFD coupling
- Hydraulic
  - Pipes, actuators, valves, sources, sinks
- Controls
  - Electric motors
  - Strain, displacement, acceleration sensors
  - System modeling/signal processing elements
  - Programmable elements

Real-Time Experiment



Virtual Experiment
as a cheap and safe
replacement
of experiment setup



Real-Time Virtual
Experiment

Simulation Improvements

Software:

- sparse matrix/vector handling during assembly
- sparse solution handling
- assembly parallelization
- solution parallelization
- hardware improvements

Model:

- topology rationalization
- constraints idealization
- deformability reduction (and elimination)

Software Improvements

Guidelines:

- beneficial for standard solution as well
- assembly/solution: ~ 70-80 vs. 25-15 % CPU time

Results: speed-up

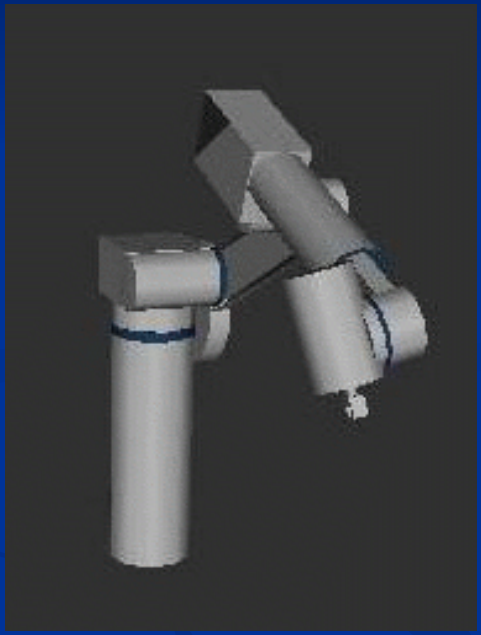
- assembly in compressed matrix form: -10/-20 %
- multi-threaded assembly: -0/15 %
- dense solver: +50/-40 %
- iterative solver (worst case limitation)
- multi-threaded solution (n.a. yet)

Overall: -20/-45 %

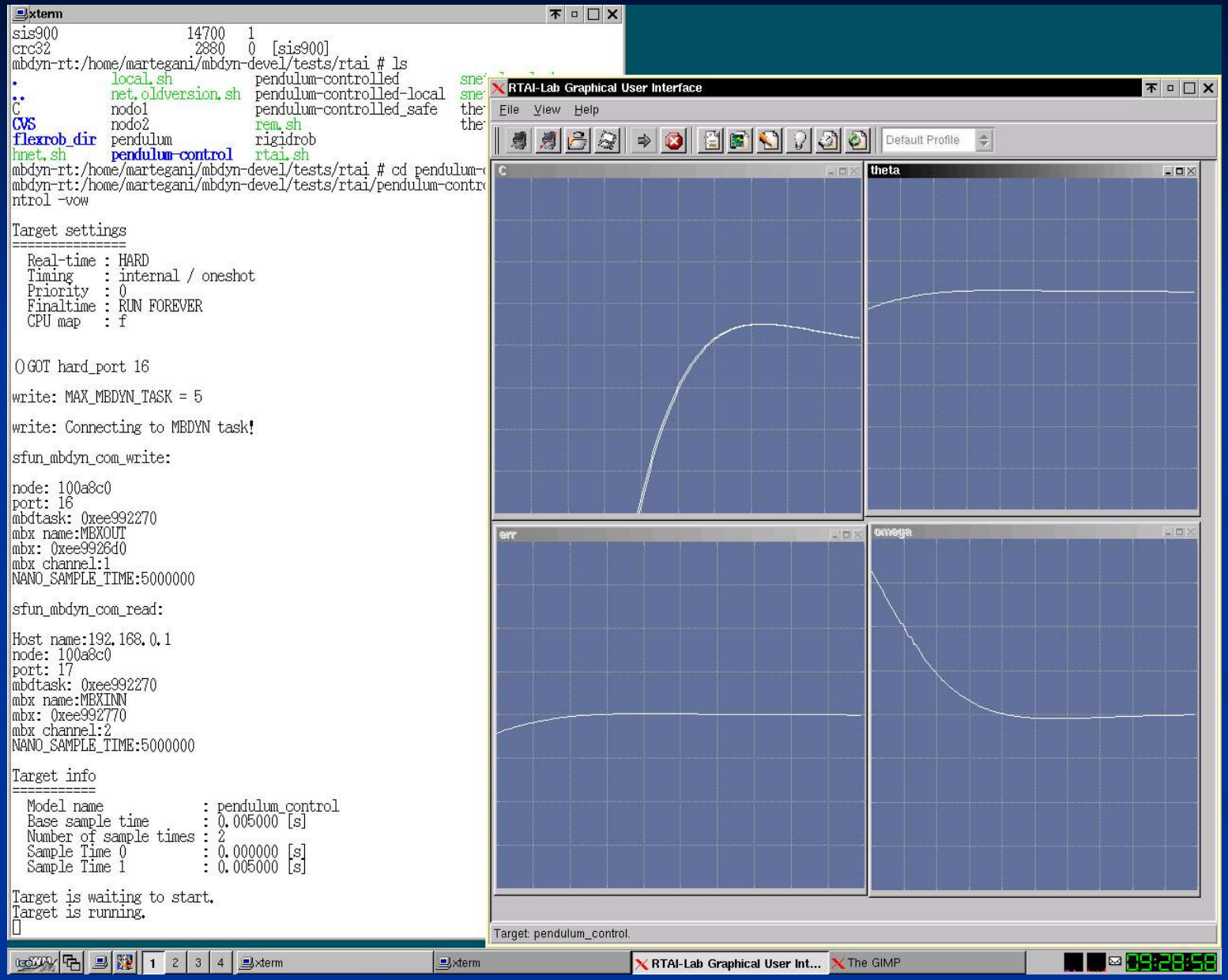
Comau robot model

Model description:

- rigid bodies, plane rotation joints
- friction
- 6 DOFs, 120 unknowns
- from 500 Hz to 2kHz (Athlon XP 2400+)



Comau control and monitor



Concluding Remarks

- General purpose real-time multibody simulation is feasible
- Performances on robot simulations meet requirements
- There is room for software/model improvements:
  - electric motors
  - feed-forward
  - parallel solution
- Real-time software optimization beneficial for conventional GP simulations as well

Previous works

- M. Attolico, P. Masarati, M. W. Nixon and P. Mantegazza, “Real-Time Multibody Analysis of Wind-Tunnel Rotorcraft Models for Virtual Experiment Purposes”, AHS 4th Decennial Specialists' Conference on Aeromechanics, Fisherman's Wharf, San Francisco, CA, January 21-23, 2004.
- M. Attolico and P. Masarati, “A Multibody User-Space Hard Real-Time Environment for the Simulation of Space Robots”, Fifth Real-Time Linux Workshop, November 9-11, 2003, Valencia, Spain.
- Acknowledgements to Matteo Martegani, Michele Attolico and Giuseppe Quaranta.