Automatic differentiation techniques

Simulation of massively controlled space telescopes

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## Inside ANTASME

<table>
<thead>
<tr>
<th>WP number</th>
<th>Workpackage title</th>
<th>Start month</th>
<th>End month</th>
<th>Leading participant n.</th>
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WP2 - Automatic differentiation techniques

Implicit code:

- Set of nonlinear equations \( f(x) = 0 \)
- Jacobian matrix \( J = \frac{\partial f}{\partial x} \) (cumbersome)

Rapid elements prototyping

- Code \( f(x) = 0 \)
- Let the code compute \( J \)

MBDyn:

- Multibody code
  - GPL
  - C++

http://www.aero.polimi.it/~mbdyn
WP2 - Automatic differentiation techniques

Automatic differentiation techniques:

- Analysis of source code (Fortran/C)
- Tape of operations (operator overloading, C++)

Requirements:

- Instrumentation of the code (operations/loops/conditions)
- Use of custom data type
- Template (C++)

Result:

- Source code analysis: compiled
- Callable subroutine: run-time
## WP2 - Survey of available libraries

<table>
<thead>
<tr>
<th>Tool</th>
<th>Language</th>
<th>License</th>
<th>Source code</th>
<th>Method</th>
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<td>Custom non-profit</td>
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<td>$$</td>
<td>Tape</td>
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**WP2 – Coding effort**

- Once for all: enable the code

```cpp
double Mat3x3::dDet(void) const
{
    double* p = (double*)pdMat;

    return p[M11]*(p[M22]*p[M33]-p[M23]*p[M32])
    +p[M12]*(p[M23]*p[M31]-p[M21]*p[M33])
}
```

```cpp
template<class T>
T Mat3x3T<T>::dDet(void) const
{
    T* p = (T*)pdMat;

    return p[M11]*(p[M22]*p[M33]-p[M23]*p[M32])
    +p[M12]*(p[M23]*p[M31]-p[M21]*p[M33])
}
```

```cpp
typedef Mat3x3T<double> Mat3x3
```

- **Element level: \( J \) (requires \( f \))**

```cpp
std::vector<T> y_dep(12);
CppAD::Independent(x_indep);
res_vec(p, x_indep, y_dep, pEl->GetLabel());
CppAD::ADFun<doublereal> f(x_indep, y_dep);
.....
J = f.Jacobian(xx); //Compute J(x)
```

```cpp
//declare dep variables
//declare indep variables
//compute f(x)
```
WP2 - Status and future work

Integration almost finished

- Templatize MBDyn: double vs. CppAD<double>
- Elements

Issues

- Rotation:
  - SO(3) -> nonlinear \( \mathbf{x} \) / body orientation
    - handled outside elements

Automatic elements

- Wheel
- Complex joint (gimball?)

Accuracy and timing tests
WP5 - Simulation of massively controlled space telescopes

- Carlo Gavazzi Space SpA
- Structural design
- A.D.S. International
- Active mirror actuators
- DIA
- Mirror deployment simulation
- Active mirror control

Images credit Carlo Gavazzi Space
WP5 – space telescope active control

- Active mirror
- Mirror
- Back-plate
- 186 co-located actuator-sensor pairs
- 2 Hz

Images credit Carlo Gavazzi Space
WP5 – space telescope active control

Background:
- MMT active secondary mirror
- Feed-forward
- Decentralized PID2

Simulation code:
- Modal dynamic
- Off-line mirror stiffness identification
- Gain optimization

- Rigid body movement?
- Non-controllable mirror flapping?
WP5 – space telescope feed-forward concept

- Static feed forward: 2 Hz
- Computed recursively
  \[ \Delta f = K(x^{k+1} - x^k_{avg}) \]
- Robust vs. \( K \)
- Requires: estimate of \( K \)
  - Identification
- Stability: PID2 (500 Hz)
WP5 – space telescope work

- Done:
  - Modified preliminary FEM model (from CGS)
  - Use actuators response function (from A.D.S.)
  - Data extraction
    - $K$ identification

Images credit Carlo Gavazzi Space
WP5 – space telescope work

• Ongoing:
  • Gain optimization

• ToDo:
  • Improve actuator model
  • Attitude control
  • Attitude and deformable mirror controls
  • Simulation of mirror deployment
  • Disturbance rejection
WP9 - Dissemination

http://www.aero.polimi.it/Antasme

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