Chrono Support for Modeling Robotic Systems

A bio-inspired robot, using Chrono::Solidworks
Robotics: an example of workflow

- Use SolidWorks 3D CAD to model the robot
- Export the 3D CAD model using the Chrono::Solidworks add-in as a Python model
- Import the Python model
  - ... in your C++ program (using the PYPARSER module in Chrono::Engine API)
  - ... in your PYTHON program (using the Chrono::PyEngine units)
- Add actuators or additional parts/links using Chrono
- Impose motion to actuators
- Simulate the mechanism
Use SolidWorks CAD to model a bio-inspired robot
SolidWorks - rigid bodies

The Chrono::SolidWorks Add-in supports:

• Assemblies of parts
  • Ex: the robot arms

• Sub-assemblies of assembles
  • Ex: the full robot
SolidWorks - rigid bodies

Hints:
• A sub-assembly by default in SW is considered a whole rigid body
  • Sub-assemblies like the robot arms would become single ChBody objects on the Chrono side...
  • Inner constraints would not be considered...

• Select the sub-assembly and use this icon of pop-up menu to switch to “flexible” SW assembly:
  • All SW parts in sub-assembly will become separate ChBody objects on the Chrono side
  • Inner constraints will be translated into ChLink constraints on the Chrono side
SolidWorks - constraints

• Use the “mates” tool to create constraints in SW
• Most SW “mates” constraints will be translated into ChLink constraints on the Chrono side:
  • Coincident (plane vs plane, plane vs point, edge vs plane, ... )
  • Parallel (plane vs plane, plane vs edge, edge vs edge, ... )
  • Parpendicular ...
  • Distance ...
  • Concentric ...

• Some SW mates are not yet supported, sorry
  • Advanced mates
  • Tangent etc.
SolidWorks - markers

- SolidWorks “coordinate systems” are translated in ChMarker objects on the Chrono side.

- This is a useful way to add custom Chrono constraints from the C++ side, later, by referencing pairs of markers.

- In our robot example: add pair of markers where you need to create ChLinkEngine objects (with Z axis aligned to the engine shaft):

- Give them a mnemonic name in SW, so it is easier to retrieve them from the C++ side:
SolidWorks - actuators

• For our spider robot example:
  • Each leg is a 3 DOF arm (like a ‘top loader’ packaging robot, without gripper)
  • We need 3 actuators (three ‘ChLinkEngine’) per leg
  • Sorry, the SolidWorks “motor” object is not yet translated into a Chrono ChLinkEngine object (planned for future releases)
  • ..so we just add couples of markers per each motor, and we’ll add the ChLinkEngine objects programmatically, later from the Chrono side
    • Two for the vertical shoulder rotation
    • Two for the up-down rotation
    • Two for the forearm rotation
SolidWorks - collision shapes

Collision shapes can be defined in the SolidWorks interface

• Each part of SolidWorks can contain multiple “solid bodies”
• Use one SW “solid body” for the shape (mass, visualization), and create others for collision shapes
• Supported collision shapes:
  • Cylinders
  • Spheres
  • Boxes
  • Convex hulls
  • (compounds of the above)
Collision shapes can be defined in the SolidWorks interface

- For the spider robot example: add a collision shape for the foot contact
  - Extrude a cylinder feature in the foot part
  - Do not merge the cylinder feature with the foot shape
  - Select the cylinder and use the “Set body as collision shape” button
  - Look how the name of the cylinder changed:
Export the 3D CAD model to a .py file

- Use the “Save as Python” button to export the model into a .py file for later use in Chrono programs

SolidWorks CAD model
SPIDER_ROBOT.SLDASM

Chrono::Python model
spider_robot.py
A peek into the spider_robot.py model

```python
import ChronoEngine_python_core as chrono
import builtins

shapes_dir = 'spider_robot_shapes/
ifar hasattr(builtins, 'exported_system_relpath'):
    shapes_dir = builtins.exported_system_relpath + shapes_dir
exported_items = []

body_0 = chrono.ChBodyAuxRef()
body_0.SetName('ground')
body_0.SetBodyFixed(True)
exported_items.append(body_0)

# Rigid body part
body_1 = chrono.ChBodyAuxRef()
body_1.SetName('M-410iB-300-12-1')
body_1.SetPos(chrono.ChVectorD(-4.07967425969663,1.53452994138092,0.579942165862929))
body_1.SetRot(chrono.ChQuaternionD(-0.0412727252884181,-0.000468569478897146,0.999147807992026,1.93556340954814e-05))
body_1.SetMass(16.1636065115335)
body_1.SetInertiaXX(chrono.ChVectorD(0.270733820597613,0.40087790867468,0.42731867141468))
body_1.SetInertiaXY(chrono.ChVectorD(0.054221068634289,0.0377110505251339,-0.0625533943672037))
body_1.SetFrame_COG_to_REF(chrono.ChFrameD(chrono.ChVectorD(-0.0294847451383035,0.131793864973377,-0.039955675141979),chrono.ChQuaternionD(1,0,0,0)))

# Visualization shape
body_1_1_shape = chrono.ChObjShapeFile()
body_1_1_shape.SetFilename(shapes_dir+'body_1_1.obj')
body_1_1_level = chrono.ChAssetLevel()
body_1_1_level.GetFrame().SetPos(chrono.ChVectorD(0,0,0))
body_1_1_level.GetFrame().SetRot(chrono.ChQuaternionD(1,0,0,0))
body_1_1_level.GetAssets().push_back(body_1_1_shape)
body_1.GetAssets().push_back(body_1_1_level)

# Collision shapes
body_1.GetCollisionModel().ClearModel()
mr = chrono.ChMatrix33D()  
mr[0,0]=0; mr[1,0]=0; mr[2,0]=-1
mr[0,1]=0; mr[1,1]=-1; mr[2,1]=0
mr[0,2]=-1; mr[1,2]=0; mr[2,2]=0
body_1.GetCollisionModel().AddCylinder(0.0891514706007005,0.0891514706007005,0.0737653824400992,chrono.ChVectorD(0.0294847451383035,0.131793864973377,-0.039955675141979),chrono.ChQuaternionD(1,0,0,0))

body_1.SetCollide(True)
exported_items.append(body_1)
```

...
Import the Python model

There are two ways to load and simulate a .py file generated by the SolidWorks add-in:

• In a C++ program – use the pyparser library from the PYTHON unit of Chrono, to load spider_robot.py with ImportSolidWorksSystem()

• In a PYTHON program – just use the chrono python modules to load spider_robot.py with ImportSolidWorksSystem()

(Not so many differences, by the way)
Import the Python model

- The Chrono::PyEngine modules must be correctly installed
  - Compile Chrono with the PYTHON unit enabled
  - If all is fine, Chrono modules will be available from the Python side, try demo_python_1.py
  - Suggested: use a Python IDE, ex. PyScripter

- Create a `demo_spider.py` program

- First: import the Chrono::PyEngine by writing

```python
import os
import math
import ChronoEngine_python_core as chrono
import ChronoEngine_python_postprocess as postprocess
import ChronoEngine_python_irrlicht as chronoirr
```
Import the Python model

• Then, use the following to load the .py model:

```python
mysystem = chrono.ChSystemNSC()

parts = chrono.ImportSolidWorksSystem('./spider_robot');

for ib in parts:
    mysystem.Add(ib);
```

• Note, do not pass “.py” suffix in ImportSolidWorksSystem()
Import the Python model

• Some components are not present in the .py model – the actuators!
• We will add them programmatically, connecting pair of ChMarker with ChLinkEngine
• Retrieve the ChMarker objects from their names as in:

```python
bbody = mysystem.SearchBody('Part3^SPIDER_ROBOT-1');
bbody.SetBodyFixed(False);
b1base = mysystem.SearchBody('M-410iB-300 -1/ArmBase-1');
b1turret = mysystem.SearchBody('M-410iB-300 -1/M-410iB-300-02-1');
b1bicept = mysystem.SearchBody('M-410iB-300 -1/M-410iB-300-03-1');
b1forearm = mysystem.SearchBody('M-410iB-300 -1/M-410iB-300-06-1');
m1_1B = b1base. SearchMarker('marker_M1_B');
m1_1A = b1turret. SearchMarker('marker_M1_A');
m1_2B = b1turret. SearchMarker('marker_M2_B');
```

• Note, look in SolidWorks GUI or in spider_robot.py if you do not remember the mnemonic names, and remember that M-410iB-300 <1> in GUI becomes M-410iB-300 -1 in code
Add actuators or additional parts/links using Chrono

• Create some f(t) motion functions to be assigned to the actuators
• ChLinkEngines will use them in ‘impose rotation mode’
• Each represents the imposed rotation of the joint [rad], as a function of time [s]
• (In a more sophisticated simulator, one can put the ChLinkEngines in ZOH ‘impose torque’ and adjust torque in real time using some PID, IK, i.e. complex controller systems)
• The f(t) functions are created from the ChFunction class hierarchy
• Interesting: use ChFunction_Sequence to queue multiple curves, and ChFunction_Repeat to make periodic functions
Add actuators or additional parts/links using Chrono

- Example of $f(t)$ functions for this example:

```cpp
period = 2;
mfunc_sineS = chrono.ChFunction_Sine(0, 1.0/period, 0.2);  # phase, frequency, amplitude
mfunc_swingSa = chrono.ChFunction_Repeat();
mfunc_swingSa.Set_fa(mfunc_sineS);
mfunc_swingSa.Set_window_length(period);
mfunc_swingSa.Set_window_start(0);
mfunc_swingSb = chrono.ChFunction_Repeat();
mfunc_swingSb.Set_fa(mfunc_sineS);
mfunc_swingSb.Set_window_length(period);
mfunc_swingSb.Set_window_start(period/2.0);
mfunc_sineD = chrono.ChFunction_Sine(0, 1.0/period, -0.2);  # phase, frequency, amplitude
mfunc_swingDb = chrono.ChFunction_Repeat();
mfunc_swingDb.Set_fa(mfunc_sineD);
mfunc_swingDb.Set_window_length(period);
mfunc_swingDb.Set_window_start(period/2.0);
mfunc_swingDa = chrono.ChFunction_Repeat();
mfunc_swingDa.Set_fa(mfunc_sineD);
mfunc_swingDa.Set_window_length(period);
mfunc_swingDa.Set_window_start(0);
Etc. . .
```
Add actuators or additional parts/links using Chrono

• Create the actuators using `ChLinkEngine` objects between couple of ChMarker objects:

```python
# Add actuators to Leg n.1

motor1_1 = chrono.ChLinkEngine();
motor1_1.Initialize(m1_1A, m1_1B);
motor1_1.Set_eng_mode(chrono.ChLinkEngine.ENG_MODE_ROTATION);
motor1_1.Set_rot_funct(mfunc_swingSa);
mysystem.Add(motor1_1);

motor1_2 = chrono.ChLinkEngine();
motor1_2.Initialize(m1_2A, m1_2B);
motor1_2.Set_eng_mode(chrono.ChLinkEngine.ENG_MODE_ROTATION);
motor1_2.Set_rot_funct(mfunc_updownA);
mysystem.Add(motor1_2);

motor1_3 = chrono.ChLinkEngine();
motor1_3.Initialize(m1_3A, m1_3B);
motor1_3.Set_eng_mode(chrono.ChLinkEngine.ENG_MODE_ROTATION);
motor1_3.Set_rot_funct(mfunc_const);
mysystem.Add(motor1_3);
```
Setup Irrlicht visualization

```python
myapplication = chronoirr.ChIrrApp(
    mysystem,
    'Test',
    chronoirr.dimension2du(1280,720))

myapplication.AddTypicalSky('./data/skybox/')
myapplication.AddTypicalCamera(
    chronoirr.vector3df(2.8,2.6,2.8),
    chronoirr.vector3df(0.0,2.6,0.0))

myapplication.AddTypicalLights()

myapplication.AddLightWithShadow(
    chronoirr.vector3df(10,20,10),
    chronoirr.vector3df(0,2.6,0),
    10 ,10,40, 60, 512);

myapplication.AssetBindAll();

myapplication.AssetUpdateAll();

myapplication.AddShadowAll();
```
The simulation loop

```python
mysystem.SetMaxItersSolverSpeed(600);
mysystem.SetSolverWarmStarting(True);
mysystem.SetSolverType(chrono.ChSolver.Type_BARZILAIBORWEIN);
myapplication.SetTimestep(0.002);

while(myapplication.GetDevice().run()):
    myapplication.BeginScene()
    myapplication.DrawAll()
    myapplication.DoStep()
    myapplication.EndScene()
```
Simulate the mechanism (walk pattern A)
Simulate the mechanism (walk pattern B – better)
Simulate the mechanism
Conclusions

• Used Chrono::SolidWorks add-in as a preprocessor
• This add-in is under development: some SolidWorks mates are not yet translated into equivalent Chrono constraints
• Exported models in .py files can be load in C++ programs or Python programs
• One can add engines, actuators etc. programmatically
• The demo_spider.py program could be written as a C++ program with minimal differences
• This is a quick demo: a more advanced simulator could include sophisticated gait algorithms, path following, PID based actuators, Simulink co-simulation, etc.
Future developments

• We are developing a new ROBOTICS module for Chrono

• Some features are already in development
  • Support for artificial vision
  • Support for sensors
  • Path following, controllers,
  • Visualization tools
  • Etc.