Presenting DualSPHysics with a Chrono Project implementation. New developments, capabilities and practical examples

RICARDO B. CANELAS¹, MOISÉS BRITO², ORLANDO G. FEAL³, JOSE M. DOMÍNGUEZ³, ALEJANDRO J.C. CRESPO³

¹MARETEC, INSTITUTO SUPERIOR TÉCNICO, LISBON, PORTUGAL

²CERIS, INSTITUTO SUPERIOR TÉCNICO, LISBON, PORTUGAL

³ENVIRONMENTAL PHYSICS LABORATORY (EPHYSLAB). UNIVERSIDADE DE VIGO, OURENSE, SPAIN



CERIS Civil Engineering Research and Innovation for Sustainability







General motivation

Mechanical **contacts** and **constrains** are ubiquitous in natural and industrial processes, ranging from simple linear mechanisms to intricate highly non-linear problems.

- DualSPHysics offers a solid-solid distributed contact discrete element method (**DCDEM**) model, but:
- Not unconditionally stable contact description
- Difficult to model intricate mechanisms
- Complex friction models hurt performance unacceptably for HPC code



Rigid bodies in DualSPHysics

Conserving the **relative positions** of a group of particles, these can be made to describe a solid body.



$$M_{I} \frac{d\boldsymbol{V}_{I}}{dt} = \sum_{k \in I} m_{k} \frac{d\boldsymbol{v}_{k}}{dt}$$
$$I_{I} \frac{d\boldsymbol{\Omega}_{I}}{dt} = \sum_{k \in I} m_{k} (\boldsymbol{r}_{k} - \boldsymbol{R}_{I}) \times \frac{d\boldsymbol{v}_{k}}{dt}$$
$$\boldsymbol{v}_{k} = \boldsymbol{V}_{I} + \boldsymbol{\Omega}_{I} \times (\boldsymbol{r}_{k} - \boldsymbol{R}_{I})$$

The **inertia tensor** is computed on the fly for the system of material points, making no assumptions on shape, *i.e.* it is **exact for the discretized system**.

Project Chrono

Project Chrono is a **physics-based** modeling and simulation **library** based on a **platform-independent**, **open-source** design - much like DualSPHsysics



- Wide set of joints (spherical, revolute joint, prismatic, universal joint, glyph, with limits, etc.)
- Unilateral constraints
- Exact Coulomb friction model, for precise stick-slip of bodies
- Springs and dampers, even with non-linear features
- Recent support for linear and nonlinear Finite Element Analysis - Euler-Bernoulli beams, bars, shells, cables.

http://projectchrono.org

Implementation on DualSPHysics

Difficulties along the (unfinished) way

- Project Chrono is a library, not an application
- Typical workflow is writing C++ code with your model, using the library API, compile and run
- Like DualSPHysics, the code is in active development

- Project Chrono is very large. Thousands of API calls are available
- Documentation is, unsurprisingly, limited (much better than most projects)
- Several key concepts are different such as coordinate systems, I/O, ...

Limited functionality is available in v4.3 – no periodic conditions; no imposed motion

Implementation on DualSPHysics





B. Chandra and M. Asai, *Verification and validation of the fluid-rigid body interaction simulation by the smoothed particle hydrodynamics method*, in Proceedings of Computational Engineering Conference JSCES, vol. 21, 2016.



DUALSPHYSICS WORKSHOP 2018 - LISBON



M. Arnold, M. Kretschmer, J. Koch, P.W. Cheng, F. Biskup et al., *A validation method for fluid-structure-interaction simulations based on submerged free decay experiments*, in The Twenty-fifth International Ocean and Polar Engineering Conference. International Society of Offshore and Polar Engineers, 2015.

Validations - II



Validations - II



Validations - II



Applications?

If it moves with and by a fluid-solid system we want to model it



How to use it?

<?xml version="1.0" encoding="UTF-8" ?>

<case app="GenCase4 v4.0.033 (14-11-2016)" date="11-07-2018 18:38:46">

<casedef>

<execution></execution>	
<special></special>	
<chrono></chrono>	
<scheme< td=""><td>escale value="1" comment="Scale used to create the initial scheme of <u>Chrono</u> objects (default=1)" /></td></scheme<>	escale value="1" comment="Scale used to create the initial scheme of <u>Chrono</u> objects (default=1)" />
<bodyf:< td=""><td><pre>ixed id="Domain" mkbound="0" modelfile="AutoActual" /></pre></td></bodyf:<>	<pre>ixed id="Domain" mkbound="0" modelfile="AutoActual" /></pre>
<bodyf.< td=""><td>loating id="Jumper" mkbound="1" modelfile="AutoActual" /></td></bodyf.<>	loating id="Jumper" mkbound="1" modelfile="AutoActual" />
<link_< td=""><td>linearspring idbodyl="Domain" idbody2="Jumper"></td></link_<>	linearspring idbodyl="Domain" idbody2="Jumper">
<pc< td=""><td>pint_fbl x="0.95" y="0.5" z="10" comment="Point in body 1" /></td></pc<>	pint_fbl x="0.95" y="0.5" z="10" comment="Point in body 1" />
<pc< td=""><td>oint_fb2 x="0.95" y="0.5" z="9.5" comment="Point in body 2" /></td></pc<>	oint_fb2 x="0.95" y="0.5" z="9.5" comment="Point in body 2" />
<s1< td=""><td>tiffness value="1000" comment="stiffness" /></td></s1<>	tiffness value="1000" comment="stiffness" />
<da< td=""><td>amping value="100" comment="damping" /></td></da<>	amping value="100" comment="damping" />
<re><re< td=""><td>est_length value="3" comment="spring equilibrium length" /></td></re<></re>	est_length value="3" comment="spring equilibrium length" />
<td>linearspring></td>	linearspring>
<parameters></parameters>	
<parameter< td=""><td>key="PosDouble" value="1" comment="Precision in particle interaction 0:Simple, 1:Double, 2:Uses and saves double (default=0)" /></td></parameter<>	key="PosDouble" value="1" comment="Precision in particle interaction 0:Simple, 1:Double, 2:Uses and saves double (default=0)" />
<parameter< td=""><td><pre>key="StepAlgorithm" value="2" comment="Step Algorithm 1:<u>Verlet</u>, 2:<u>Symplectic</u> (default=1)" /></pre></td></parameter<>	<pre>key="StepAlgorithm" value="2" comment="Step Algorithm 1:<u>Verlet</u>, 2:<u>Symplectic</u> (default=1)" /></pre>
<parameter< td=""><td>key="VerletSteps" value="40" comment="<u>Verlet</u> only: Number of steps to apply Euler <u>timestepping</u> (default=40)" /></td></parameter<>	key="VerletSteps" value="40" comment=" <u>Verlet</u> only: Number of steps to apply Euler <u>timestepping</u> (default=40)" />
<parameter< td=""><td><pre>key="Kernel" value="2" comment="Interaction Kernel 1:Cubic Spline, 2:Wendland (default=2)" /></pre></td></parameter<>	<pre>key="Kernel" value="2" comment="Interaction Kernel 1:Cubic Spline, 2:Wendland (default=2)" /></pre>
<parameter< td=""><td><pre>key="ViscoTreatment" value="1" comment="Viscosity formulation 1:Artificial, 2:Laminar+SPS (default=1)" /></pre></td></parameter<>	<pre>key="ViscoTreatment" value="1" comment="Viscosity formulation 1:Artificial, 2:Laminar+SPS (default=1)" /></pre>
<parameter< td=""><td><pre>key="<u>Visco</u>" value="0.01" comment="Viscosity value" /></pre></td></parameter<>	<pre>key="<u>Visco</u>" value="0.01" comment="Viscosity value" /></pre>
<parameter< td=""><td><pre>key="ViscoBoundFactor" value="0" comment="Multiply viscosity value with boundary (default=1)" /></pre></td></parameter<>	<pre>key="ViscoBoundFactor" value="0" comment="Multiply viscosity value with boundary (default=1)" /></pre>
<parameter< td=""><td><pre>key="DeltaSPH" value="0.1" comment="DeltaSPH value, 0.1 is the typical value, with 0 disabled (default=0)" /></pre></td></parameter<>	<pre>key="DeltaSPH" value="0.1" comment="DeltaSPH value, 0.1 is the typical value, with 0 disabled (default=0)" /></pre>
<parameter< td=""><td>key="#Shifting" value="0" comment="Shifting mode 0:None, 1:Ignore bound, 2:Ignore fixed, 3:Full (default=0)" /></td></parameter<>	key="#Shifting" value="0" comment="Shifting mode 0:None, 1:Ignore bound, 2:Ignore fixed, 3:Full (default=0)" />
<parameter< td=""><td><pre>key="#ShiftCoef" value="-2" comment="Coefficient for shifting computation (default=-2)" /></pre></td></parameter<>	<pre>key="#ShiftCoef" value="-2" comment="Coefficient for shifting computation (default=-2)" /></pre>
<parameter< td=""><td>key="#ShiftTFS" value="1.5" comment="Threshold to detect free surface. Typically 1.5 for 2D and 2.75 for 3D (default=0)" /></td></parameter<>	key="#ShiftTFS" value="1.5" comment="Threshold to detect free surface. Typically 1.5 for 2D and 2.75 for 3D (default=0)" />
<parameter< td=""><td><pre>key="RigidAlgorithm" value="3" comment="Rigid Algorithm 1:SPH, 2:DEM, 3:Chrono (default=1)" /></pre></td></parameter<>	<pre>key="RigidAlgorithm" value="3" comment="Rigid Algorithm 1:SPH, 2:DEM, 3:Chrono (default=1)" /></pre>
<parameter< td=""><td>key="FtPause" value="0.0" comment="Time to freeze the floatings at simulation start (<u>warmup</u>) (default=0)" units comment="seconds" /></td></parameter<>	key="FtPause" value="0.0" comment="Time to freeze the floatings at simulation start (<u>warmup</u>) (default=0)" units comment="seconds" />
<parameter< td=""><td>key="CoefDtMin" value="0.05" comment="Coefficient to calculate minimum time step <u>dtmin=coefdtmin*h/speedsound</u> (default=0.05)" /></td></parameter<>	key="CoefDtMin" value="0.05" comment="Coefficient to calculate minimum time step <u>dtmin=coefdtmin*h/speedsound</u> (default=0.05)" />
<parameter< td=""><td>key="#DtIni" value="0.0001" comment="Initial time step (default=h/<u>speedsound</u>)" units_comment="seconds" /></td></parameter<>	key="#DtIni" value="0.0001" comment="Initial time step (default=h/ <u>speedsound</u>)" units_comment="seconds" />
<parameter< td=""><td>key="#DtMin" value="0.00001" comment="Minimum time step (default=<u>coefdtmin</u>*h/<u>speedsound</u>)" units_comment="seconds" /></td></parameter<>	key="#DtMin" value="0.00001" comment="Minimum time step (default= <u>coefdtmin</u> *h/ <u>speedsound</u>)" units_comment="seconds" />
<parameter< td=""><td>key="#DtFixed" value="DtFixed.dat" comment="Dt values are loaded from file (default=disabled)" /></td></parameter<>	key="#DtFixed" value="DtFixed.dat" comment="Dt values are loaded from file (default=disabled)" />
<parameter< td=""><td><pre>key="DtAllParticles" value="0" comment="Velocity of particles used to calculate DT. 1:All, 0:Only fluid/floating (default=0)" /></pre></td></parameter<>	<pre>key="DtAllParticles" value="0" comment="Velocity of particles used to calculate DT. 1:All, 0:Only fluid/floating (default=0)" /></pre>
<parameter< td=""><td><pre>key="TimeMax" value="10" comment="Time of simulation" units_comment="seconds" /></pre></td></parameter<>	<pre>key="TimeMax" value="10" comment="Time of simulation" units_comment="seconds" /></pre>
<parameter< td=""><td>key="TimeOut" value="0.01" comment="Time out data" units_comment="seconds" /></td></parameter<>	key="TimeOut" value="0.01" comment="Time out data" units_comment="seconds" />
<parameter< td=""><td>key="IncZ" value="0.5" comment="Increase of Z+" units comment="decimal" /></td></parameter<>	key="IncZ" value="0.5" comment="Increase of Z+" units comment="decimal" />
<parameter< td=""><td>key="PartsOutMax" value="1" comment="%/100 of fluid particles allowed to be excluded from domain (default=1)" units comment="decimal" /></td></parameter<>	key="PartsOutMax" value="1" comment="%/100 of fluid particles allowed to be excluded from domain (default=1)" units comment="decimal" />
<parameter< td=""><td>key="RhopOutMin" value="700" comment="Minimum <u>thop</u> valid (default=700)" units comment="kg/m^3" /></td></parameter<>	key="RhopOutMin" value="700" comment="Minimum <u>thop</u> valid (default=700)" units comment="kg/m^3" />
<parameter< td=""><td>key="RhopOutMax" value="1300" comment="Maximum <u>rhop</u> valid (default=1300)" units comment="kg/m^3" /></td></parameter<>	key="RhopOutMax" value="1300" comment="Maximum <u>rhop</u> valid (default=1300)" units comment="kg/m^3" />
<parameter< td=""><td>key="DomainFixed" value="-3:-1:0:5:2:10" comment="The domain is fixed with the specified values (xmin:ymin:zmin:xmax:ymax:zmax)" units comment="metres (r</td></parameter<>	key="DomainFixed" value="-3:-1:0:5:2:10" comment="The domain is fixed with the specified values (xmin:ymin:zmin:xmax:ymax:zmax)" units comment="metres (r

</case>

How to use it?

<?xml version="1.0" encoding="UTF-8" ?>

<case app="GenCase4 v4.0.033 (14-11-2016)" date="11-07-2018 18:38:46">

<casedef>

<execution>

<special> <chrono>

<schemescale value="1" comment="Scale used to create the initial schem <bodyfixed id="Domain" mkbound="0" modelfile="AutoActual" /> <bodyfloating id="Jumper" mkbound="1" modelfile="AutoActual" /> <link linearspring idbody1="Domain" idbody2="Jumper">

<damping value="100" comment="damping" />

<rest_length value="3" comment="spring equilibrium length" /> </link_linearspring>

</chrono>

</special>

<parameters>

<parameter key="PosDouble" value="1" comment="Precision in particle intera
<parameter key="StepAlgorithm" value="2" comment="Step Algorithm 1:<u>Verlet</u>,
<parameter key="VerletSteps" value="40" comment="<u>Verlet</u> only: Number of st
<parameter key="Kernel" value="2" comment="Interaction Kernel 1:Cubic Spli
<parameter key="ViscoTreatment" value="1" comment="Viscosity formulation 1
<parameter key="Visco" value="0.01" comment="Viscosity value" />

<parameter key="ViscoBoundFactor" value="0" comment="Multiply viscosity va</pre> <parameter key="DeltaSPH" value="0.1" comment="DeltaSPH value, 0.1 is the</pre> <parameter key="#Shifting" value="0" comment="Shifting mode 0:None, 1:Igno</pre> <parameter key="#ShiftCoef" value="-2" comment="Coefficient for shifting</pre> <parameter key="#ShiftTFS" value="1.5" comment="Threshold to detect free</pre> <parameter key="RigidAlgorithm" value="3" comment="Rigid Algorithm 1:SPH,</pre> <parameter key="FtPause" value="0.0" comment="Time to freeze the floatings</pre> <parameter key="CoefDtMin" value="0.05" comment="Coefficient to calculate</pre> <parameter key="#DtIni" value="0.0001" comment="Initial time step (default</pre> <parameter key="#DtMin" value="0.00001" comment="Minimum time step (defaul)</pre> <parameter key="#DtFixed" value="DtFixed.dat" comment="Dt values are loade</pre> <parameter key="DtAllParticles" value="0" comment="Velocity of particles value="0"</pre> <parameter kev="TimeMax" value="10" comment="Time of simulation" units com</pre> <parameter key="TimeOut" value="0.01" comment="Time out data" units commer</pre> <parameter key="IncZ" value="0.5" comment="Increase of Z+" units comment="</pre> <parameter key="PartsOutMax" value="1" comment="%/100 of fluid particles a</pre> <parameter key="RhopOutMin" value="700" comment="Minimum rhop valid (defau</pre> <parameter key="RhopOutMax" value="1300" comment="Maximum rhop valid (defa</pre> <parameter key="DomainFixed" value="-3:-1:0:5:2:10" comment="The domain is</pre> </parameters>

Time: 4.13 s

CaseBungieJump

" />

</execution>

```
<mainlist>
            <setshapemode>real | bound</setshapemode>
            <setmkbound mk="5" />
            <drawbox>
                <boxfill>bottom | left | right | front | back</boxfill>
                <point x="0.0" y="0.0" z="0.0" />
               <size x="10.0" v="10.0" z="7.0" />
            </drawbox>
            <setdrawmode mode="full" />
            <setmkbound mk="0" />
            <drawcylinder radius="0.05" mask="1">
                <point x="5" v="5" z="5" />
               <point x="5" y="6" z="5" />
            </drawcylinder>
            <setmkbound mk="1" />
            <drawcylinder radius="0.05" mask="1">
                <point x="5" y="6" z="5" />
               <point x="5" y="7" z="5" />
            </drawcylinder>
            <setmkbound mk="2" />
            <drawcylinder radius="0.05" mask="1">
                <point x="5" y="7" z="5" />
               <point x="5" v="8" z="5" />
            </drawcylinder>
            <setmkbound mk="3" />
            <drawcylinder radius="0.05" mask="1">
                <point x="5" v="8" z="5" />
               <point x="5" y="9" z="5" />
            </drawcylinder>
           <shapeout file="" reset="true" />
        </mainlist>
   </commands>
</geometry>
<floatings>
   <floating mkbound="0-3" relativeweight="1.0" property="steel" />
</floatings>
<properties>
   cyropertyfile file="Floating Materials.xml" path="materials" />
</properties>
```

<mainlist></mainlist>	
<setshapemode>real bound</setshapemode>	<pre></pre>
<setmkbound mk="5"></setmkbound>	<pre></pre>
<drawbox></drawbox>	<pre></pre>
<pre><boxfill>bottom left right front back</boxfill></pre>	
<pre><point x="0.0" y="0.0" z="0.0"></point></pre>	<pre><pre>cproperties></pre></pre>
<pre><size v="10.0" x="10.0" z="7.0"></size></pre>	<pre><pre>propertyfile file="Floating_Materials.xml" path="materials" /></pre></pre>
<pre><setdrawmode mode="full"></setdrawmode></pre>	
<setmkbound mk="0"></setmkbound>	<execution></execution>
<pre><drawcvlinder mask="1" radius="0.05"></drawcvlinder></pre>	<pre><special></special></pre>
<pre><pre><pre><pre><pre><pre><pre><pre></pre></pre></pre></pre></pre></pre></pre></pre>	<pre><chrono></chrono></pre>
<pre><pre><pre><pre><pre><pre><pre><pre></pre></pre></pre></pre></pre></pre></pre></pre>	<pre><schemescale arm"="" comment="Scale used to create the initial scheme of Chrono objects (default=</pre></td></tr><tr><td></drawcvlinder></td><td><bodyfloating id=" mkbound="0-3" value="1"></schemescale></pre>
<pre><setmkbound mk="1"></setmkbound></pre>	<link_spheric idbodyl="arm0"></link_spheric>
<pre><drawcvlinder mask="1" radius="0.05"></drawcvlinder></pre>	<rotpoint comment="Point for rotation" x="5" y="5" z="5"></rotpoint>
<pre><pre><pre><pre><pre><pre><pre><pre></pre></pre></pre></pre></pre></pre></pre></pre>	<pre><stiffness comment="Torsional stiffness [N/rad]" value="0"></stiffness></pre>
<pre><pre><pre><pre><pre><pre><pre><pre></pre></pre></pre></pre></pre></pre></pre></pre>	<pre><damping comment="Torsional damping [-]" value="0"></damping></pre>
<setmkbound mk="2"></setmkbound>	<pre><link_spheric idbody2="arm1" idbodyl="arm0"></link_spheric></pre>
<pre><drawcvlinder mask="1" radius="0.05"></drawcvlinder></pre>	<rotpoint comment="Point for rotation" x="5" y="6" z="5"></rotpoint>
<pre><pre><pre><pre><pre><pre><pre><pre></pre></pre></pre></pre></pre></pre></pre></pre>	<pre><stiffness comment="Torsional stiffness [N/rad]" value="0"></stiffness></pre>
<pre><pre><pre><pre><pre><pre><pre><pre></pre></pre></pre></pre></pre></pre></pre></pre>	<pre><damping comment="Torsional damping [-]" value="0"></damping></pre>
<setmkbound mk="3"></setmkbound>	<pre><link_spheric idbody2="arm2" idbodyl="arm1"></link_spheric></pre>
<pre><drawcylinder mask="1" radius="0.05"></drawcylinder></pre>	<rotpoint comment="Point for rotation" x="5" y="7" z="5"></rotpoint>
<pre><pre><pre><pre><pre><pre><pre><pre></pre></pre></pre></pre></pre></pre></pre></pre>	<pre><stiffness comment="Torsional stiffness [N/rad]" value="0"></stiffness></pre>
<pre><point v="9" x="5" z="5"></point></pre>	<pre><damping comment="Torsional damping [-]" value="0"></damping></pre>
<pre><shapeout file="" reset="true"></shapeout></pre>	<link_spheric_idbodyl="arm2"_idbody2="arm3"></link_spheric_idbodyl="arm2"_idbody2="arm3">
	<pre>rotpoint x="5" y="8" z="5" comment="Point for rotation" /></pre>
	<pre><stiffness comment="Torsional stiffness [N/rad]" value="0"></stiffness></pre>
/geometry>	<pre><damping comment="Torsional damping [-]" value="0"></damping></pre>
floatings>	
<floating mkbound="0-3" property="steel" relativeweight="1.0"></floating>	
/floatings>	
properties>	<pre><parameters></parameters></pre>
<propertyfile file="Floating_Materials.xml" path="materials"></propertyfile>	
/properties> 0</td <td>case></td>	case>



<floatings>

<floating mkbound="0-3" relativeweight="1.2" property="steel" />

<floating mkbound="4" relativeweight="2.5" property="steel" />

<floating mkbound="51-66" relativeweight="1.2" property="soft-wood" />

</floatings>

<properties>

<propertyfile file="Floating_Materials.xml" path="materials" />

<links>

<link mkbound="10" property="steel" comment="Property for the fixed bound" />
</links>

</properties>

</casedef>

<execution>

<special>

<chrono>

<schemescale value="1" comment="Scale used to create the initial scheme of Chrg <bodyfixed id="domain" mkbound="10" modelfile="AutoActual" modelnormal="invert" <bodyfloating id="arm" mkbound="0-3" />

<bodyfloating id="ball" mkbound="4" modelfile="AutoActual" /><bodyfloating id="box" mkbound="51-66" modelfile="AutoActual" /><link spheric idbodyl="arm0">

<rotpoint x="5" y="5" z="5.2" comment="Point for rotation" />
<stiffness value="0" comment="Torsional stiffness [N/rad]" />
<damping value="0" comment="Torsional damping [-]" />

</link_spheric>

<link_spheric idbody1="arm0" idbody2="arm1">

<rotpoint x="6" y="5" z="5.2" comment="Point for rotation" /> <stiffness value="0" comment="Torsional stiffness [N/rad]" /> <damping value="0" comment="Torsional damping [-]" />

</link_spheric>

<link_spheric idbodyl="arm1" idbody2="arm2">

<rotpoint x="7" y="5" z="5.2" comment="Point for rotation" /> <stiffness value="0" comment="Torsional stiffness [N/rad]" /> <damping value="0" comment="Torsional damping [-]" />

</link_spheric>

<link_spheric idbody1="arm2" idbody2="arm3">

```
<rotpoint x="8" y="5" z="5.2" comment="Point for rotation" />
<stiffness value="0" comment="Torsional stiffness [N/rad]" />
<damping value="0" comment="Torsional damping [-]" />
```

</link_spheric>

<link_spheric idbody1="arm3" idbody2="ball">

<rotpoint x="9" y="5" z="5.2" comment="Point for rotation" /> <stiffness value="0" comment="Torsional stiffness [N/rad]" /> <damping value="0" comment="Torsional damping [-]" />

</link_spheric>

</chrono>





</special>

</chrono>

<bodyfixed id="domain" mkbound="0" /> <bodyfloating id="hinged" mkbound="1-5" /> k hinge idbodyl="hinged1" idbody2="hinged2"> <rotpoint x="0.5" y="0" z="0.2" comment="Point for rotation" /> <rotvector x="0" y="1" z="0" comment="Vector direction for rotation" /> <stiffness value="750" comment="Torsional stiffness" /> <damping value="50" comment="Torsional damping" /> </link hinge> k hinge idbodyl="hinged2" idbody2="hinged3"> <rotpoint x="0.5" y="0" z="0.4" comment="Point for rotation" /> <rotvector x="0" y="1" z="0" comment="Vector direction for rotation" /> <stiffness value="750" comment="Torsional stiffness" /> <damping value="50" comment="Torsional damping" /> </link hinge> k hinge idbodyl="hinged3" idbody2="hinged4"> <rotpoint x="0.5" y="0" z="0.6" comment="Point for rotation" /> <rotvector x="0" y="1" z="0" comment="Vector direction for rotation" /> <stiffness value="750" comment="Torsional stiffness" /> <damping value="50" comment="Torsional damping" /> </link hinge> k hinge idbody1="hinged4" idbody2="hinged5"> <rotpoint x="0.5" y="0" z="0.8" comment="Point for rotation" /> <rotvector x="0" y="1" z="0" comment="Vector direction for rotation" /> <stiffness value="750" comment="Torsional stiffness" /> <damping value="50" comment="Torsional damping" /> </link hinge> <link hinge idbodyl="hinged5"> <rotpoint x="0.5" y="0" z="1.0" comment="Point for rotation" /> Time: 0.00 s <rotvector x="0" y="1" z="0" comment="Vector direction for rotation" /> <stiffness value="750" comment="Torsional stiffness" /> <damping value="50" comment="Torsional damping" /> </link hinge>



CaseFlexibleGate

Going through the examples – Case 3

<schemescale value="1" comment="Scale used to create the initial scheme of Chrono objects (default=1)" />

<special>

<chrono>

<special>

<chrono> <schemescale value="1" comment="Scale used to create the initial scheme of Chrono objects (default=1)" /> <bodyfloating id="arm" mkbound="0-3" /> <link pointline idbodyl="arm0"> <rotpoint x="5.8" y="0" z="1.5" comment="Point for rotation" /> <rotvector x="0" v="0" z="1" comment="Vector direction for rotation" /> <stiffness value="0" comment="Torsional stiffness" /> <damping value="0" comment="Torsional damping" /> CasePelamis </link pointline> <link hinge idbodyl="arm0" idbody2="arm1"> <rotpoint x="7.15" y="0" z="1.5" comment="Point for Time: 0.00 s <rotvector x="0" y="1" z="0" comment="Vector direction <stiffness value="0" comment="Torsional stiffness" /</pre> <damping value="0" comment="Torsional damping" /> </link hinge> <link hinge idbodyl="arm1" idbody2="arm2"> <rotpoint x="8.45" y="0" z="1.5" comment="Point for <rotvector x="0" y="1" z="0" comment="Vector direction <stiffness value="0" comment="Torsional stiffness" /: <damping value="0" comment="Torsional damping" /> </link hinge> <link hinge idbodyl="arm2" idbody2="arm3"> <rotpoint x="9.75" y="0" z="1.5" comment="Point for <rotvector x="0" v="1" z="0" comment="Vector direction <stiffness value="0" comment="Torsional stiffness" /: <damping value="0" comment="Torsional damping" /> </link hinge> </chrono> </special>



<chrono>

<savedata value="0.02" comment="Saves CSV with data exchange for each time interval (0=all steps)" /> <bodyfixed id="domain" mkbound="1" modelfile="AutoActual" modelnormal="invert" /> <bodyfloating id="head" mkbound="2" modelfile="AutoActual" /> <bodyfloating id="body" mkbound="3" modelfile="AutoActual" /> <bodyfloating id="arm left" mkbound="4" modelfile="AutoActual" /> <bodyfloating id="arm right" mkbound="5" modelfile="AutoActual" /> <bodyfloating id="forearm left" mkbound="6" modelfile="AutoActual" /> <bodyfloating id="forearm right" mkbound="7" modelfile="AutoActual" /> <bodyfloating id="leg left" mkbound="8" modelfile="AutoActual" /> <bodyfloating id="leg right" mkbound="9" modelfile="AutoActual" /> <bodyfloating id="calf left" mkbound="10" modelfile="AutoActual" /> <bodyfloating id="calf right" mkbound="11" modelfile="AutoActual" /> <!-- Elbows --> k hinge idbodyl="arm left" idbody2="forearm left"> <rotpoint x="0" y="-.18" z="-.381" comment="Point for rotation" /> <rotvector x="1" y="0" z="0" comment="Vector direction for rotation" /> <stiffness value="0" comment="Torsional stiffness" /> <damping value="0" comment="Torsional damping" /> <friction value="0" comment="Friction coefficient" /> </link hinge> k hinge idbodyl="arm right" idbody2="forearm right"> <rotpoint x="0" y=".18" z="-.381" comment="Point for rotation" /> <rotvector x="1" v="0" z="0" comment="Vector direction for rotation" /> <stiffness value="0" comment="Torsional stiffness" /> <damping value="0" comment="Torsional damping" /> <friction value="0" comment="Friction coefficient" /> </link hinge> <!-- Knees --> k hinge idbodyl="leg left" idbody2="calf left"> <rotpoint x="0" v="-.055" z="-.837" comment="Point for rotation" /> <rotvector x="0" y="1" z="0" comment="Vector direction for rotation" /> <stiffness value="0" comment="Torsional stiffness" /> <damping value="0" comment="Torsional damping" /> <friction value="0" comment="Friction coefficient" /> </link hinge> k hinge idbodyl="leg right" idbody2="calf right"> <rotpoint x="0" y=".055" z="-.837" comment="Point for rotation" /> <rotvector x="0" v="1" z="0" comment="Vector direction for rotation" /> <stiffness value="0" comment="Torsional stiffness" /> <damping value="0" comment="Torsional damping" /> <friction value="0" comment="Friction coefficient" /> </link hinge> <!-- Neck --> <link spheric idbodyl="head" idbody2="body"> <rotpoint x="0" v="0" z="-.125" comment="Point for rotation" /> <stiffness value="0" comment="Torsional stiffness" /> <damping value="0" comment="Torsional damping" />

</link_spheric>



<chrono>

<schemescale value="1" comment="Scale used to create the initial scheme of Chrono objects (default=1)" />

<bodyfloating id="cube" mkbound="51-53" modelfile="AutoActual" />

<bodyfixed id="tank" mkbound="0" modelfile="AutoActual" modelnormal="invert" />

</chrono>



</chrono>

<chrono>

<link_hinge idbody1="weel" idbody2="bucket4">
 <rotpoint x="3.65" y="0" z="3.0" comment="Point for rotat
 <rotvector x="0" y="1" z="0" comment="Vector direction fo
 <stiffness value="0" comment="Torsional stiffness" />
 <damping value="100" comment="Torsional damping" />
 <friction value="0" comment="Friction coefficient" />

<damping value="100" comment="Torsional damping" />
<friction value="0" comment="Friction coefficient" />
</link hinge>

</link_hinge>
<link_hinge idbody1="weel" idbody2="bucket3">
<link_hinge idbody1="weel" idbody2="bucket3">
<rotpoint x="7.35" y="0" z="3.0" comment="Point for rotat
<rotvector x="0" y="1" z="0" comment="Vector direction fo
<stiffness value="0" comment="Torsional stiffness" />

ink_ninge iabody1="weel" iabody2="budket2">

/>

/>

/>
//>
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
//
///
///
///
///
///
///
///
///
///
///
///
///
///
///
///
////
////
///
////
/////
//////
/////
/////

</link_hinge>
<link_hinge idbody1="weel" idbody2="bucket2">

<link_hinge idbodyl="weel">
 <rotpoint x="5.5" y="0" z="3.0" comment="Point for rotati
 <rotvector x="0" y="1" z="0" comment="Vector direction fo
 <stiffness value="0" comment="Torsional stiffness" />
 <damping value="500" comment="Torsional damping" />
 <friction value="0" comment="Friction coefficient" />

<bodyfixed id="domain" mkbound="0"/><bodyfloating id="weel" mkbound="1"/>

<savedata value="0.01" comment="Saves CSV with data exchange for each time interval (0=all steps)" />

Going through the examples – Case 8



<friction </link hinge>







What is available in 4.3

Contact modelling

- Able to replace the DCDEM model available in DualSPHysics
- Uses two values: restitution and kinematic friction coefficient, using the input system already in place for the DEM model

Mechanical restrictions

- Hinge, spherical, point line (spherical on an axis) and linear springs
- All of these can be defined with a corresponding stiffness and damping parameters
- No limits to restrictions

A separate project implements the classes that abstract the Chrono library calls.

This project is currently compiled as a .dll shared library that DualSPHysics uses.

For 4.3, this dll is a black box, we are not releasing the source code yet.

Conclusions and future work

- DualSPHysics now supports kinematic constraints
- The implemented constrains allow you to model many different and complex cases, since you can combine them
- •The contact algorithms are now much more robust and resolution-independant

- DualSPHysics abstracts the Chrono Project for the user
- Bodies going through periodic planes are not supported yet
- Bodies with imposed motion are not used in the interaction yet
- Meshes with high triangle counts lead to high computation times (only CPU yet)

- Deformable elements (elastoplaticity)
- Execution of contact problems should be doable in GPU