Non-Physical Simulation of Gears and Modifiable Connections in Virtual Reality

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Abstract: In this paper we present the functional (non-physical) modeling of gear couplings and adjustable building parts in a system for Virtual Assembly. In this system the user can multimodally interact in a CAVE-like setup using gesture and speech to instantiate, connect and modify building parts. The building parts, which are modeled in an XML description language, can have parametrically modifiable subparts, and ports as assembly points. The parameters of these parts can be linked in order to simulate hinges and the transmission ratio of gears. Special nodes in the scene graph – so called *Constraint Mediators* – are established to watch the port connections for propagation and adjustment of the motion of the connected parts. After the virtual assembly of such parts the user can interactively explore the functional effects of the simulation, e.g., the propagation of movements.

Keywords: Virtual Assembly, Virtual Prototyping, Mechanical Simulation, Multimodal Interaction

1. Introduction

Virtual Prototyping, i.e., building a preliminary design in Virtual Reality, can be used to test fittings of mechanical parts and the suitedness of sizes to human users. Additional to such a pure design of static building parts we present a system, that can handle complex scalable building parts and that allows to explore the moveable parts of a newly designed object. The system is built with the AVANGO-Toolkit [8], which uses the OpenGL Performer Scene Graph and provides additional fields and field connections for a data-flow graph orthogonal to the scene graph.

As pointed out in [3], a physical simulation of the movements of the gears is time consuming and real-time simulation is only possible for a small number of components. To achieve real-time processing for an interactive virtual assembly system a functional simulation of the gear couplings is used in our approach. Instead of employing an external graph structure for representing the geometric constraints in a separate constraint solver (as in [6], [9] and [4]) we use local constraint solvers, so called *Constraint Mediators*, to define and observe local geometric constraints. With this concept of locally defined constraints between field values in the scene graph it is possible to merge the constraints and the geometry description in one data-structure.

A set of parametrically modifiable port connections were devised whose parameters can be linked via special field connections and therefore can act as gears or hinges. With these parts it is possible to simulate diverse rotational and translational transmissions like, e.g., pinion gears. A first kind of Constraint Mediators we devised concern special field connections, which allow multiple bindings to one destination field and which can propagate field values in both directions of the binding.

A different kind of Constraint Mediators observes the port connections of the parts and propagates the movement between the linked building parts. They are established when connecting two ports of different building parts. The mediators can restrict the possible movements of a part and can propagate the translation and rotation from one part to the connected parts.

The building parts and the gears – which are special parts with internal coupled parametric changeable subparts and ports – are described in an XML notation. This notation allows also for simple CSG modeling and a scaling mechanism for complex scalable objects whose subparts can be scaled individually.

2. Short Overview of the Assembly System

In our system for multimodal assembly the user can interact with a CAVE-like Virtual Environment to construct virtual prototypes. The goal is to provide an environment where the user can act naturally in a virtual construction scenario, similar to the interaction of two humans using gestures and speech.

Fig.1: User building a "Citymobile"-vehicle in a CAVE-like virtual environment

Figure 1 shows a user performing a scaling operation on an already mounted wheel by grasping the wheel with both hands and moving them apart to enlarge the wheel.

Our main prerequisites for this work are gesture recognition, integration of gesture and speech [5], and the augmentation of virtual scenes with semantic information like, e.g., the connection properties, color and shape information for the reference analysis and scaling behavior of building parts and assembled aggregates [1].

All building parts are described in an XML description, which is translated by an XSLT-script [7] to SCHEME-scripts interpretable by AVANGO. The system can interactively build a visual representation that can be altered and scaled in real time. The concrete polygonal representation is built by the CAD tool ACIS [2]. A wrapper for this tool reads the XML description and uses the ACIS programming interface to compute the polygonal boundary, using the new parameters of the building parts after completition of each interaction. The real-time visualization is replaced after the computation is finished.

Additionally to assembling building parts and choosing their size and color, the user can explore the dynamic behavior of the assembled functional groups, e.g., by turning the steering wheel to see the effect on the front wheels of the vehicle.

3. The Concept of Constraint Mediators

In the normal case field connections as used in VR-Frameworks like AVANGO are directed, such that the data flows from the source to the destination field. This concept of directed field connections guarantees a directed data-flow between the components and allows an event-driven computation of field values. This concept also requires that each destination field has only one source field and that circular structures in the field connections are inhibited, to avoid conflicting values. Figure 2 shows a directed field connection and two connections which are forbidden, because they would either form a loop or establish two connections to the same field. Forbidden connections are marked as dotted arrows in Fig. 2.

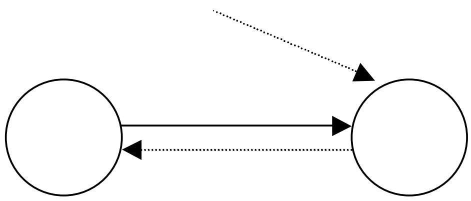

Fig. 2: A directed field connection, with forbidden connections (dotted arrows)

In some cases it is convenient to have connections that transport data in both directions and that can have multiple connections for one destination field. For example when modeling a gear with directed field connections between the two rotating ports, it is only possible to let the rotation of one port affect the rotation of the other port, but not in the other way, without remodeling the field connection between the two ports.

In order to enable a two-way communication between two fields, new components were developed to mediate between the field values. Since the normal field connections have restrictions as described above, the two fields are connected via a Constraint Mediator (CM), as shown in Figure 3.

The connections of the CM to the fields are not established with the normal field connections, but instead the CM hold references to the fields to get and set their values independent of the normal field value propagation. By this technique CMs can be used in conjunction with normal field connections in one data-flow graph.

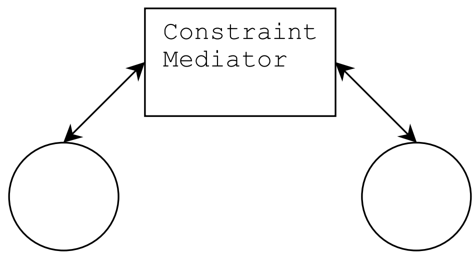

Fig. 3: Two fields connected via a Constraint Mediator

Since now there is no longer a simple master-slave relationship between the two fields, the changes of the field values have to be detected and analyzed in the CM and then routed to the corresponding fields where required. If constraint propagation conflicts occur in the implicitly created constraint graph or if conflicts are generated by the interaction of the user, the values of both controlled fields can change externally. The Constraint Mediator has then to resolve possible conflicts and either override one value, or find a reasonable average of values, or keep the previous values for both fields. The individual behavior, when coping with such conflicting field values, depends on the application and is selectable by the user.

The Constraint Mediator can obey different relationships between the two values, from simple test for equality to complex functional relations. Different CMs were built which can e.g. mediate between simple floating point values, three-dimensional vectors, and transformation matrices.

4. Simulation of gears and hinges

To create dynamically changeable building parts, subparts can be augmented additionally to the scaling with parametrical rotations and translations. A simple parametrical rotation of a subpart can result in a hinge. If rotations or translations are coupled, it is possible to simulate different kind of gears. For the coupling of these parameters we again use Constraint Mediators.

```
<Part name="Gear1">
  <color red="0.4" green="0.4" blue="0.5"/>
  <SubPart name="Spherebody" genRep="sphere .2">
    <Geometry csg="+">
      <Sphere radius="0.2">
    </Geometry>
  </SubPart>
  <SubPart name="Hole1">
    <Geometry translation="0.2 0 0" csg="-">
      <Cylinder radius="0.15" length="0.1" />
    </Geometry>
    <Parametric>
      <Rotation name="RotateHole1" axis="1 0 0" />
    </Parametric>
    <Port name="Hole1_Port " type="pointport"
        translation="0.15 0 0"/>
  </SubPart>
  <SubPart name="Hole2_Angle">
    <Parametric>
      <Rotation name="Angle" anglemin="70"
          anglemax="180" axis="0 0 1"/>
    </Parametric>
    <SubPart name="Hole2">
      <Geometry translation=".2 0 0"  CSG="-">
        <Cylinder radius="0.15" length="0.1" />
      </Geometry>
      <Parametric>
        <Rotation name="RotateHole2" axis="1 0 0"
        connect="RotateHole1" transmission="2.0"/>
      </Parametric>
      <Port name="Hole2_Port " type="pointport"
          translation="0.15 0 0"/>
    </SubPart>
  </SubPart>
</Part>
```

Fig. 4: The XML-description of a rotational coupled gear with adjustable angle

Gears are described in the same way as the other building parts in an XML-notation. Constraint Mediators are automatically established where two parameters of the described gear were coupled.

The parameters for the rotations and translations affect the matrix of the subpart. The matrix of this subpart and its parameters are also coupled via CMs so that the parameter changes the matrix, but also changes of the matrix can have an effect on the parameter. This is needed to enable propagation of the movement of connected parts through the gear, as will be described in Section 5.

4.1. Example 1: A rotationally coupled gear

Figure 4 shows an example of an XML-notation describing a gear consisting of a spherical body with two cylindrical holes, which act as ports for connecting other building parts. The angle between the holes' center axes is adjustable between 70 and 180 degrees. The adjustment of the angle is achieved by creation of the parametrical subpart "Hole2_Angle", whose parameter adjusts the angle between the two holes. This parameter results in a field for each instance of the gear and can be set in the range of the minimum and maximum values given in the XML-description.

The other two parametrical subparts: "RotateHole1" and "RotateHole2" are used to simulate a transmission ratio of the two port rotations. Each parameter describes a rotation of the hole along its main axis. The "connect" attribute of the "Rotation"-tag in the XML-description causes the establishment of a Constraint Mediator to maintain a fixed ratio of the two rotation angles. Since the transmission value in this example is set to 2.0, the CM for simple float values detects changes of the rotation value of each port and multiplies, respectively divides, it by 2 and sets the rotation value of the other port.

Figure 5 shows the visualization of this gear with two different angles. The conical objects inside the two holes represent the possible connection points.

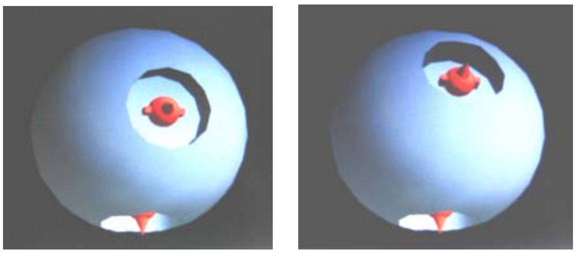

Fig. 5: Gears with angles of 90 and 120 degrees

4.2. Example 2: A pinion gear

This example shows a coupling of rotational and translational parameters. One parameter is used to rotate the front port around its main axis as in the example above. The other parameter translates a cylindrical subpart along its axis. These two parameters are linked by a CM with an appropriate transmission ratio to propagate the rotation of the hole to the translation of the rod and vice versa.

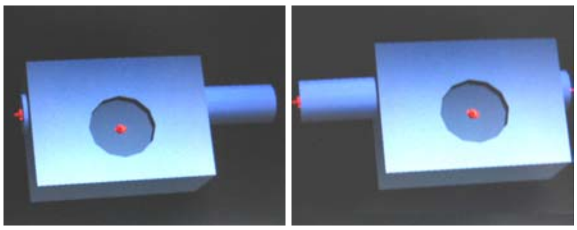

Fig. 6: A pinion gear, in two positions

Figure 6 shows a pinion gear in two extreme positions, the front port rotated at maximum to the right or to the left, resp.

5. Constraint Mediators for port connections

Additional to the usage inside gears CMs can be used to establish and maintain port connections of the building parts.

5.1. Simple, fixed connections

CMs for transformation matrixes can establish spatial link relations between objects which are more complex than the usual parent/child relations in a scene graph. For example connected ports of two building parts can be monitored by *matrix mediators* to keep the relative locations of the two parts. In this case the root transformations of the two objects are linked by a matrix mediator which observes the local relative positions of the two connected ports. The constraint mediator watches the port positions for equality and alters the root translations of the connected objects appropriately to maintain the connected ports in the same place. A diagram of the mediator in the scene graph is shown in Figure 7.

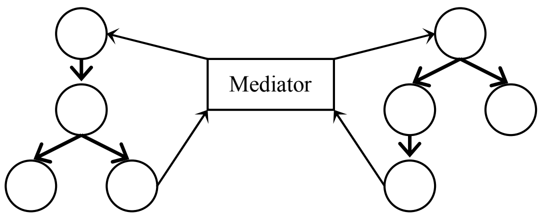

Fig. 7: A part of a SG with a Mediator watching the port positions

Both objects can act as master or slave such that movements of one object always causes the other object to move, in order to simulate a fixed connection of the two ports.

5.2. Connections propagating movement in a gear chain

Mixed Constraint Mediators can couple, e.g., rotation values of the gear with a rotation matrix of a corresponding port, and vice versa. By this it is possible to link a rotation of a part, connected with a port of a gear, with the rotation value of that gear and, further, with a given transmission ration to the second port of the gear.

When a user turns an object while the application is in a special testing mode, the object will not follow directly the movement of the user. Instead, movements of the objects are restricted to the degrees of freedom which are defined by the port connections. In this sense the connections to a port of a gear are special because the movement of the port can be coupled to a parameter of the gear. For example turning a handle, which is connected to "Hole1" of the gear in the example shown in Fig. 5, will cause a change of the rotation parameter of both holes. The rotation of the port is restricted to the main axis of the hole and the restriction is propagated back to the handle.

As shown in Figure 8, the rotation of the handle is propagated by a CM which watches the field connection to the gear, then analyzed and restricted by another CM which couples the rotation matrix of the port and the internal rotation parameter of this port. This parameter is – as explained in Section 4.1 – coupled via a Constraint Mediator to the rotation parameter of the second port and finally propagated to the rotation matrix of this port and to the building parts connected to this port.

Since the mediators can propagate the field values in both directions, it is also possible to affect the rotation of the handle by changing the rotation of the part connected to the other port of the gear.

5.3. An example of an assembled gear chain

In this example (Fig. 9) we see assembled parts of a steering using the gears explained in Section 4.1 and 4.2. Turning the steering wheel results in a rotation of the rod between the two gears and finally in a translation of the two connected horizontal rods, as shown in Figure 9. These rods are connected to two gears which convert the translation into the steering direction of the front wheels.

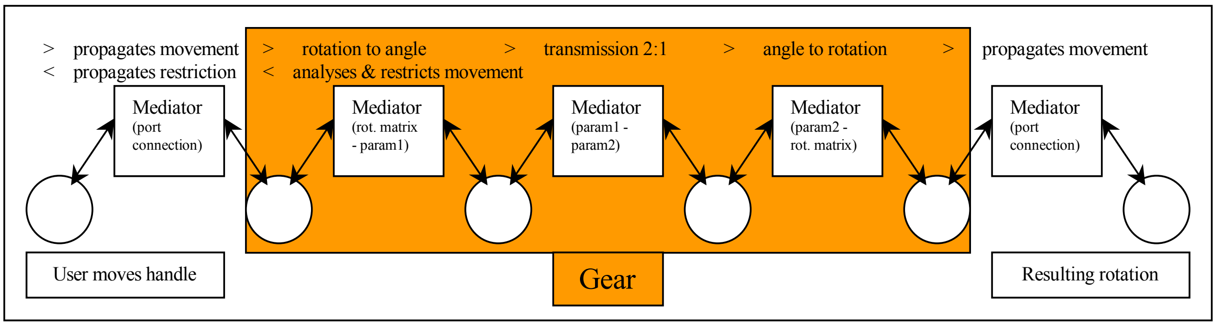

Fig. 8: A chain of CMs propagating a rotation action though a gear

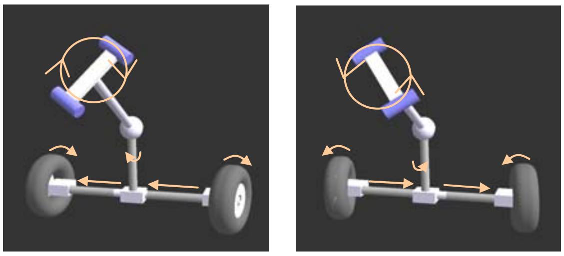

Fig. 9: A Part of a steering mechanism with two gears

By the upper gear having an adjustable angle, it is possible to fit the height of the steering wheel, by simply modifying the field value for this angle, to users of different body sizes. With the visualization in the CAVE-like Virtual Environment it is possible to get an indication of the suitedness of the assembled vehicle. Figure 10 shows two possible angles of the upper gear.

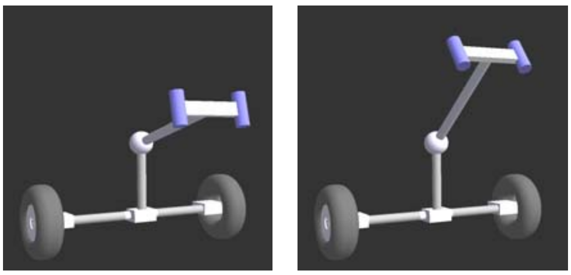

Fig. 10: Height adjustment of the steering wheel

6. Results and Outlook

In this paper we presented a system for simulating gears and hinges in a virtual assembly system. It allows a rapid virtual prototyping by modifying and assembling predefined building parts. New building parts can be defined in a rather simple way by using an XML-description which is processed by the system. Parametrically changeable parts allow users to fit sizes and shapes of the parts interactively. The functional simulation of gears allows the examination of moveable parts of the virtual prototype by visualizing the propagation of movements in an assembled gear chain.

By our new method of constraint mediators, we could successfully deal with the problem of conflicts while propagating local constraints. However, in some cases it cannot be predicted precisely *how* the conflicts are resolved. A global monitoring system which can modify the conflict solving properties of the single Constraint Mediators could lead to a more controllable behavior.

Further work is expected to lead to a simulation of moveable parts where the clearance of the subparts can be explored by detecting collision of these parts with fixed building parts. The user is supposed to get, e.g., an acoustic feedback if the tires collide with the chassis of the vehicle, when turning the steering wheel.

7. Acknowledgement

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8. Literature

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