A dataset of thin-walled deformable objects for manipulation planning

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***Abstract*—Datasets of object models with many variants of each object are required for manipulation and grasp planning using machine learning and simulation methods. This work presents a parametric model generator for thin-walled deformable or solid objects found in household scenes, such as bottles, glasses and other containers. Two datasets are provided that resemble real objects and contain a large number of variants of realistic bottles.**

INTRODUCTION

Large datasets of object models are needed for machine learning, simulation and testing/verification. In this work, we present a dataset of object models for thin-walled objects, such as bottles, glasses, vases and other containers typically found in households and offices. The models are created artificially to resemble real objects, based on a parametric object model generator. This generator is capable to build structures typically found on the above-mentioned objects. By sampling of the parameter space, many variants of an object can be created, which is especially important for machine learning applications. Starting from a surface model, a volumetric mesh is generated by adding (thin) walls and special structures, such as reinforcements. Elastic materials are considered by using appropriate material parameters on the mesh level.

Alternatively, object models could be obtained by scanning real objects, for instance using [1]. While this approach works with almost any object shape, it exhibits a number of problems: The scanning process is time-intensive and partially manual, provides only surface models and typically results in smoothing of geometric details, which hides properties that are especially important for manipulation. Most important, it is not possible to obtain large numbers of variations for an object or an object class. Other approaches, such as [2], retrieve object models from online databases. Like that, huge datasets of potentially high quality may be obtained, but the other disadvantages remain.

We use the presented models for planning of grasp configurations on deformable objects [3], and for haptic object classification during grasping (unpublished work). In both works, deformation characteristics are determined by simulation based on Finite Elements (FEM), using the presented models. In [3], we propose to calculate local stiffness features, which are also included in this dataset.

DATASET OF THIN-WALLED OBJECTS

Grasp and manipulation planning requires accurate geometric object models. Feasible grasp configurations for a given geometry can be obtained by simulation, see e.g. [4]. In order to evaluate the performance of a manipulation planner, large datasets of object models are required. For most approaches using supervised learning, many variants of the same object or object class are needed in addition. Deformable objects, which are very common in human environments, demand even more detailed models that describe not only the surface geometry, but also the inner structure of an object and elasticity parameters of the used material. In order to benefit from exiting tools and databases for surface models, volumetric models are built here based on surface models. This process relies on additional information or assumptions about objects, which may be available from priors, context, object databases or partly from measurements. Mostly, these assumptions are ambiguous, such that several volumetric models correspond to one surface model. In this work, we consider deformable or rigid containers or packages with thin walls – such as plastic bottles for drinks, cleaning agents etc. The stiffness of such objects is strongly connected to their geometry and varies within a large range along their surface.

Object models may be generated either artificially, i.e. with a construction program, or measured from a real object. Typical simulation workflows rely on the former approach, which ensures accurate (noise-free) geometry as well as complete knowledge of the inner structure and material parameters. For objects in household and office environments such models are usually not available. Their structure may be described by a surface model for the outer surface and additional parameters, such as wall thickness, material type and contents. These parameters are either specified manually or obtained from priors (e.g. semantic information), assumptions or haptic exploration of real objects. Generally, there are multiple options for structural or material parameters, such that multiple volumetric models are built from one surface model.

Volumetric representations are built from surface models by adding a second surface, creating a thin-walled structure. The space between these surfaces is meshed with tetrahedra and refined using TetGen [5]. Additionally, thin-walled containers exhibit typical structures such as bottle caps, dents or reinforcement rings. The latter structure is often found at the top end of bottlenecks or plastic cups. These structures are integrated in the volumetric model, resulting in additional object variants. Many containers can be closed with a cap, i.e. they have two different states. Deformation characteristics may change considerably depending on this state. In closed state, the mass of liquids and gasses enclosed in the container is fixed, which results in a pressure towards the inner surface on compression. As a result, the object becomes much "harder" for large deformations.

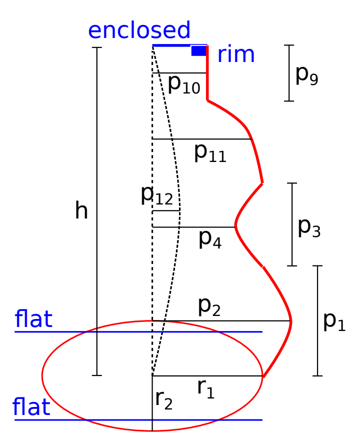

Fig. 1: Parameters of the model generator

Fig. 2: Artificial dataset (right) built according to real objects (left). Coloring represents local stiffness, see text.

Here, a model generator is used that generates artificial object models based on parametrized geometric primitives, structural parameters and material parameters. The primitives are used to create sections of the object. The considered objects are solids of revolution or built on a base area which resembles an ellipse or rounded rectangle. Side walls may be modeled as splines revolving around the base area. We select appropriate ranges for each parameter value manually for each object class to obtain realistic geometries. This approach makes it straight-forward to obtain a large number of object variations by sampling of various parameters, i.e. changing the relations of fundamental dimensions, the positions of salient or turning points, local curvature as well as the extent of convex or concave structures. Such variations may result in considerable changes of deformation behavior and provide a sufficient number of samples required for machine learning approaches.

Model generation

The model generator is based on solids of revolutions, which are subsequently adapted by the modifiers presented below. The revolving curve is made of up to four cubic sections of variable height and convexity, a tapering and a neck of smaller radius. The object is formed, so to say, by stacking convex or concave rings on top of each other. This represents the fact that most artificial bottles and containers are designed based on splines and may include knees.

The model generator uses the following parameters and respective modifiers, see Fig. 1:

$r_{1,2}$ Radius of the rotational solid. The optional second value allows to create objects with an elliptic base area.

h Height of the object.

p_{2i+1} Relative height of curve section i with $i \in [0, 3]$

p_{2i+2} Relative change of radius at the center of section i, i.e. creates convex ($i < 0$) or concave ($i > 0$) sections.

$p_{9,10}$ Relative height and radius of the bottleneck, i.e. the top section of the object.

p_{11} Convexity of the tapering below the neck – defined similar as for the lower sections. The height of this section is chosen automatically.

p_{12} Shift the y-position as a function of the object height. The parameter gives the maximum shift at relative height 0.5.

$thick$ Wall thickness

rim Add a rim (reinforcement structure) to the top of the object

$flat$ Create partially flat walls by clamping the y-value of points, i.e. $y \leftarrow \pm flat$ for $|y| > flat$.

$dent$ Adds a dent to one side of the object at height $h = dent$. Contrary to the rim, this structure results in a reduced local stiffness.

$enclosed$ Close the top of the object, i.e. add a "cap".

res Approximate distance between mesh points (resolution)

$material\_e, \_nu, \_density$ Elasticity parameters

The parameters for the objects in a named dataset are specified in `db_parameters.m`. To create a dataset, run this file and follow the instructions. A sampling range can be specified for each parameter, using the syntax $\{name, sampling, start, end\}$, where `name` is the name of the respective parameter. The code generates one model for all possible combinations of parameters values.

The following datasets will be available on http://www.lmt.ei.tum.de:

A) Artificial dataset built to resemble commercially available plastic bottles and cups with a low number of variants per object, see Fig. 2.
B) As above, but with about 50-100 variants of each object. The set of variants for one object may be considered one object class.
C) Ca. 2000 bottles generated by sampling the generator parameters within reasonable ranges. There is no notion of object class in this dataset.

Datasets contain the surface and volumetric mesh for each object, as well as the local stiffness maps (see above) for A. The parameters used for each model are stored in `parameters.mat`. The generator code is available upon request. In order to obtain reasonably sized meshes, the sampling resolution is set to 5 mm, which results in very flat tetrahedra in the volumetric mesh. If required, finer meshes may be generated by remeshing, for instance using TetGen [5].

Conclusion

In this work, a dataset of thin-walled objects typically found in household and office scenes is presented. Deformable and rigid objects such as bottles, cups and other containers made e.g. of plastic, glass or metal are considered. Models are created artificially, using a parametric model generator based on solids of revolutions and specific modifiers for typical structures. Many variants of an object can be generated, which is helpful for machine learning, simulation and verification of grasping or manipulation algorithms.

References

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