Topological and Geometric Beautification of Reverse Engineered Geometric Models

ACM Symposium on Solid Modeling and Applications 2004

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http://www.langbein.org/research/BoRG/

Abstract

Boundary representation (B-rep) models reverse engineered from 3D range data suffer from various inaccuracies caused by noise in the measured data and the model building software. Beautification aims to improve such models in a post-processing step solely working with the B-rep model. The improved model should exhibit topological and geometric regularities representing the original, ideal design intent. An overview of a beautification system suitable for improving the topology and the geometry of low to medium complexity reverse engineered models is presented.

Reverse Engineering

- Extract sufficient information from physical objects to reconstruct CAD models for a particular purpose (e.g. redesign, reproduction, quality control)
- For certain applications like redesign: reconstructed models should exhibit exactly the same geometric properties present in the original, ideal design
- Reconstruct models bounded by planes, spheres, cylinders, cones, tori with sharp edges and fixed-radius rolling ball blends

Data Capture

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Preprocessing

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Segmentation & Surface Fitting

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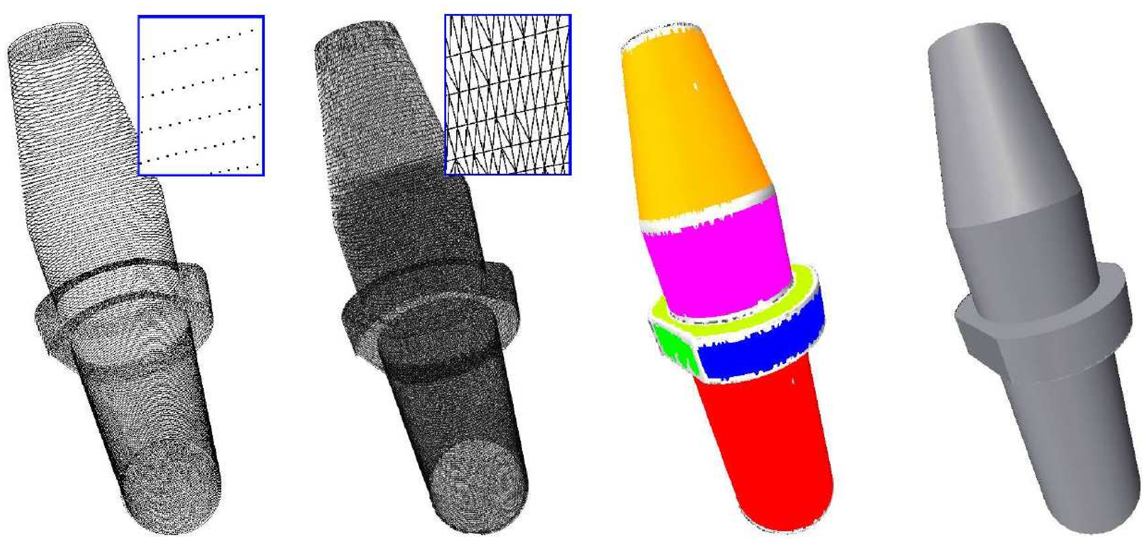
CAD Model Creation



Beautification

- Reverse engineered models exhibit intended regularities (e.g. symmetries) only approximately due to
  - inaccuracies in the measured data
  - approximation and numerical errors
  - possible wear of the object
- Beautification aims to automatically improve such models in a post-processing step
  - Use initially reconstructed, valid B-rep model with analytic, natural surfaces
  - Determine further information about the design intent from this model automatically
  - Improve geometry and topology of the model using this information without further reference to the point data
- Change of the model should be small: just enough to impose approximate regularities on the model which are present within a small tolerance

Beautification Process

I. **Detecting topological defects**: small faces, sliver faces, short edges, gaps, etc. are identified.

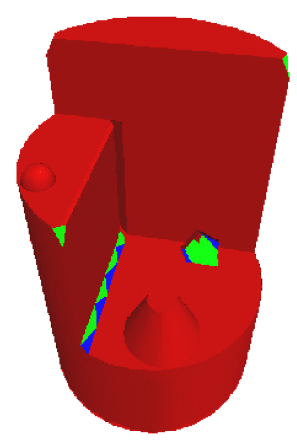
II. **Adjusting the topology**: topological defects are repaired by replacing faces with edges, edges with vertices, extending existing faces, etc. appropriately. The realisability of these changes is tested by verifying the solvability of a constraint system.

III. **Detecting approximate geometric regularities**: approximate symmetric arrangements of faces, vertices, directions, etc. in the geometry are detected. Exact conditions for approximate regularities are used rather than arbitrary tolerances.

IV. **Selecting geometric regularities**: a consistent set of geometric regularities likely to describe the model's design in terms of constraints is selected. Methods to determine the solvability of constraint systems, and the likelihood of a regularity being part of the ideal design are employed.

V. **Rebuilding an improved model**: an improved model is rebuilt from the solution to the constraint system.

Topological Beautification



- For typical reverse engineered models, topological defects are localised
  - Interaction between topological defects is limited to local faces
  - Allows to repair topological defects in well-defined sequence
- List of topological defects in the order they are detected / repaired:
  1. Gaps in a single face
  2. Gaps crossing an edge
  3. Gaps spanning multiple faces
  4. Pinched faces
  5. Chains of small faces
  6. Sliver faces (long thin faces)
  7. Chains of short edges
  8. Adjacent faces with the same geometry
  9. Isolated small faces
  10. Merging edges
  11. Isolated short edges
  - Given this particular order, certain defects are known not be present at each stage, having been repaired earlier
  - Not all possible defects, but only problems likely to arise in reverse engineering are considered
  - Adjust undesirable topology rather than repair incorrect topology
- Notion of "small" required to identify undesirable topology

Geometric Beautification

- Adjust geometry so that the model exhibits exact intended geometric regularities which may only be approximately present in the raw model
- Also ensure geometry is consistent with topological changes

Geometric Regularities

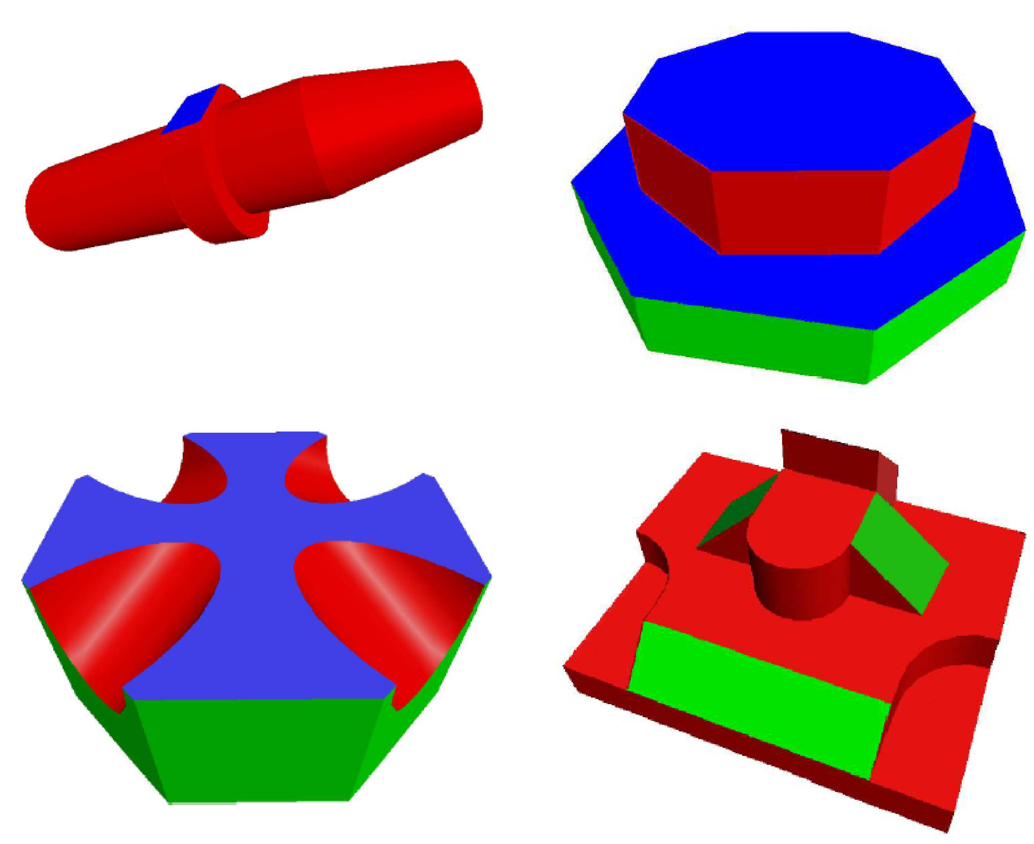
- Regularities are described as symmetries of *features*
  - Features are properties of B-rep elements which change in a similar way to the element itself under isometric transformations
  - Seek approximate symmetries of features as points in a feature space
- Approximate regularities are approximate symmetries described as approximately distance preserving permutations of features at tolerance levels where a local match implies a global match

Features	Regularity	Symmetries
Direction	Parallel directions	Identity
	Symmetries of directions	Isometries
	Rotational symmetries of directions like in regular prisms and pyramids	Rotations
Axis	Aligned axes	Identity
	Parallel axes arranged equi-spaced along lines and grids	Translations
	Parallel axes arranged symmetrically on cylinders	Rotations
	Axes intersecting in a point	Identity
Position	Equal positions	Identity
	Point set symmetries	Isometries
	Equi-spaced positions arranged on a line or a grid	Translations
	Positions arranged symmetrically on a circle	Rotations
	Equal positions when projected on a special line or plane	Identity
Length / Angle	Equal scalar parameters	Identity
	Special scalar parameter values	(special value)
	Simple integer relations	(special value)

Regularity Selection

- Add regularities in *priority* order as constraint sets to a constraint system describing the complete model
- Priority is weighted average of
  - a measure for the numerical accuracy to which the regularity's is present in the raw model
  - measure for the desirability of the regularity type
- Regularities are selected if the constraint system remains solvable
  - Solvability of constraint system is determined by a degrees-of-freedom based approach
- Rebuild model based on numerical solution of the constraint system and beautified topology
  - Generate new faces from solution
  - Intersect faces and build new model based on beautified topology

Experiments



- Major regularities, like global symmetries, orthogonal systems, etc. are imposed exactly on the model
- Depending on the tolerance settings, specific parameter values and minor regularities are not always reconstructed according to the original design
- As the raw models are approximate, there is always some uncertainty about the actual design intent