Title:
Defeaturing Sheet Metal Part Model based on Feature Information

Authors:
Yogesh H. Kulkarni, *kulkarniyh12.mech@coep.ac.in, College of Engineering Pune, India
Ravi K. Gupta, rkgiisc@gmail.com, Ecole Centrale de Nantes - IRCCyN CNRS 6597, France
Anil Sahasrabudhe, director@coep.ac.in, College of Engineering Pune, India
Mukund Kale, mukund_kale@hotmail.com, Siemens PLM, Pune, India
Alain Bernard, alain.bernard@irccyn.ec-nantes.fr, Ecole Centrale de Nantes - IRCCyN CNRS 6597, France

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Introduction:

Complex models prepared in CAD applications are often simplified before using them in downstream applications like CAE, shape matching, multi-resolution modeling, etc. In CAE, the thin-walled models are often abstracted to a midsurface for quicker analysis. Computation of the midsurface has been observed to be effective when the original model is defeatured to its gross shape.

Many existing defeaturing methods [8] typically resort to syntactic pattern recognition or similar approaches to first recognize the features on the solid body represented by B-rep or mesh and then remove them and heal the gaps. In Feature-based CAD models, features being readily available and suppressible, the critical challenge remains of correct identification of them, based on the application context. Existing methods which leverage feature information [7] appear to use the complete feature parameters to decide the suppressibility. This gives incorrect selections, as in many cases, some portion of the features are consumed and are not part of the final shape.

Main Idea:

In defeaturing of a feature-based CAD model, the relevance of each feature is measured by an evaluation metrics [2]. The evaluation metrics used in this study is divided into two classes, viz. application context-specific criteria (Phase I) and geometric reasoning-based criteria (Phase II). This work focuses on the sheet metal domain as an example of application context-specific criteria for defeaturing, for the end-use of finding the gross shape needed for computing the midsurface.

- **Phase I - Defeaturing based on the application context**: In this study, rules based on the sheet metal features taxonomy are used to decide the suppressibility of the features.
- **Phase II - Defeaturing based on geometric reasoning**: This phase starts with the final Brep for identifying the remnant portions of the features, and those whose sizes are below the threshold are identified for suppression.

The combined method (Phase I & II) is called as "**Smarf**" (**S**heet **M**etal and **R**emnant **F**eature). Following sections present the algorithms for both phases in details.

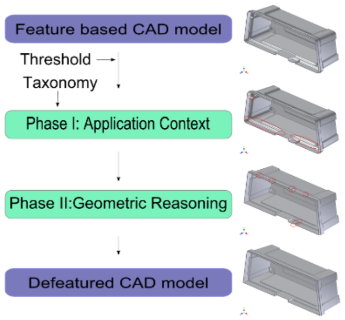


Fig. 1: Overall Defeaturing Process

Phase I: Defeaturing based on the application context:

The concept of "gross shape" is subjective and hard to quantify. Thus formulating the rules for identification of suppressible features is the most critical step that affects the output of defeaturing. Apart from similar classifications in the literature, a thorough analysis of inputs from various surveys with engineers and experts on the field was done with respect to the midsurface quality metrics, such as preservation of medial-ness, problems, errors, etc. Proposed taxonomy (Fig. 2) is the result of this analysis.

Sheet Metal Features Taxonomy:

Several researchers [3,4] have worked on sheet metal feature taxonomies for various downstream applications. Our work is developing a taxonomy for defeaturing (and will be elaborated in the full paper) of sheet metal models to find an overall/simplified shape. In this paper sheet metal features are classified (Fig. 2) for the purpose of defeaturing as follows:

- **Primary Features**: Constituents of the main shape of the body. Features that can exist independently and are created in the initial operations. These are not suppressed, irrespective of their sizes as they form the principal/gross shape and removing these would create the missing midsurface patches. Some examples are:
    - Face-Wall
    - Flange
    - Bend
- **Secondary Features**: Features are placed on the primary features and created after them. These are suppressed, based on their relative size with respect to the size of the whole part. Smaller features unnecessarily create problems in the geometric computation of the midsurface, so they need to be suppressed. Some examples are:
    - Stamping
    - Cutout
    - Emboss
- **Tertiary/Auxiliary Features**: Decorative or helpers and are not part of the main shape but modify the local geometry (point/edge). So they can be suppressed irrespective of their sizes. Examples are:
    - Lip
    - Rest
    - Letterings
- **Feature Groups**: These are an array of features and are modeled together as a single group. Suppression criteria applied is evaluated on the collective group and not on an individual feature. Some examples are:
    - Mirror
    - Patterns

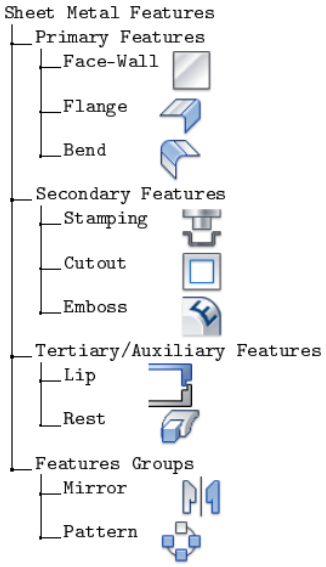


Fig. 2: Taxonomy for Gross Shape.

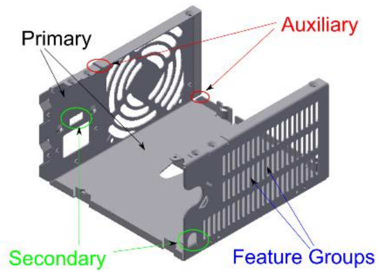


Fig. 3: Examples of the classified types.

Examples of these features are presented in a sheet metal part model as shown in Fig. 3.

Defeaturing Sheet Metal model:

The algorithm to identify the candidate sheet metal features for defeaturing from the input feature based CAD model is outlined as below:

Algorithm to identify candidate features for de-featuring based on Sheet Metal feature taxonomy:

- A List (***sl***) initialized to which the suppressible features are added.
- The model feature tree is traversed and the candidate features for suppression are identified based on a set of heuristic criteria such as "Primary features are not to be suppressed", "Secondary features, if small, are selected" etc. (Fig. 4).
- The identified features are added to ***sl***.
- The ***sl*** is presented to the user for verification and changes, if necessary.
- Features in ***sl*** are suppressed
- The model is regenerated and Defeaturing Effectiveness is computed using Eqn. 1.

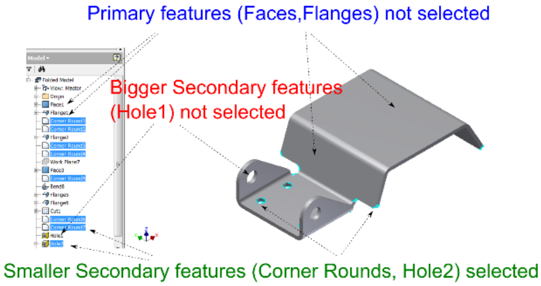


Fig. 4: Selection of features based on Taxonomy.

Phase II: Defeaturing based on Geometric Reasoning:
In the feature-based design paradigm, the CAD model is built step-by-step using features at each step. Feature parameters are used to compute the 'canonical' (tool-body) volume first, which is then booleaned to the model built till then. During this operation, some portion of the canonical volume may get consumed, leaving behind the remaining (remnant) volume in the final solid (Fig. 6).

Identification of suppressible features based on the feature volume computed from the full feature parameters yield incorrect results as the final shape may not retain the full feature volume. Thus this work proposes a new geometric reasoning approach based on the magnitude of remnant feature volume (Fig. 7).

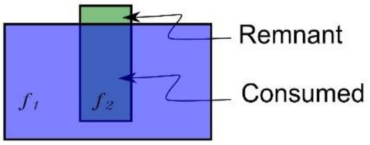


Fig. 6: Remnant and Consumed portions of feature volume of f_2.

Algorithm to identify candidate features for de-featuring based on Remnant Feature method:

- Faces of the final body are traversed.
- For each remnant face, its owning feature is extracted via attributes stored on them.
- Clusters/Groups of faces are built based on the owning features as shown in Fig. 7. The dotted portion in a cluster represents the Consumed Feature, whereas the encircled portion is the Remnant feature.

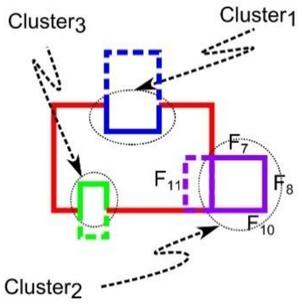


Fig. 7: Formation of Clusters.

Clusters	Size	Feature
Cluster$_1$	0.25	Extrude$_2$
Cluster$_2$	0.25	Extrude$_3$
Cluster$_3$	0.125	Hole$_1$

Tab. 1: Evaluating Cluster sizes.

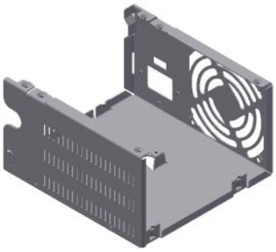
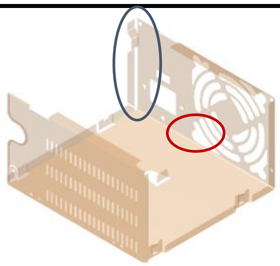
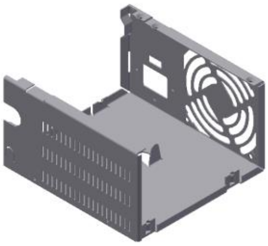
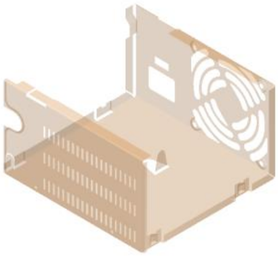
- Size of the cluster can be calculated by various methods like Influence Volume (obtained as a difference of the volume, if the feature is suppressed and then unsuppressed) or the union of bounding-boxes, etc. This work uses **summation of the areas of the remnant faces** (Tab. 1) as the Size criterion.
- Each cluster-owning feature(s) is added to ***sl*** based on the threshold value given by the user.
- The ***sl*** is presented to the user for verification and changes, if necessary.
- Features in ***sl*** are suppressed.
- The model is regenerated and Defeaturing Effectiveness is computed as below.

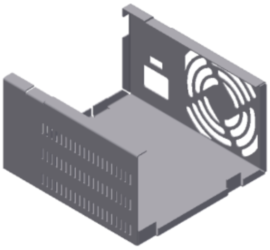
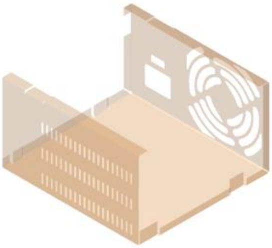
Effectiveness of Defeaturing:
In this work, the effectiveness of defeaturing is computed by measuring **Percentage reduction in the number of the faces**. More the percentage more effective is the defeaturing process. Features can also be used in place of faces to form another criterion for measuring the effectiveness.

- Total number of faces in the original part (*nF*)
- Number of sheet metal features suppressed in Phase I (*nS*)
- Number of faces left after Phase I (*mF*)
- Number of features suppressed in Phase II (*nR*)
- Number of faces left after Phase II (*rF*)
- Defeaturing Effectiveness (*pR*) while keeping the overall shape intact (%)

$$pR = \left(1 - \frac{rF}{nF}\right) X\ 100 \qquad (1)$$

Results:
Following test case shows effect of defeaturing on the quality of the midsurface. Size threshold used here is **10%** of the summation of face-areas of all the faces in the original body.

	Model	Midsurface	Explanation
Original/ Input			Gaps in the midsurface. Two of the gaps are marked (**blue** and **red**).
Output of Phase I and input to Phase II			Although the number of missing gaps in the midsurface has reduced (**red** gap is filled), but the gaps between the surface patches (**blue** gap) is still seen. These gaps are marked.

Output of Phase II	 	Most of the gaps are filled and the output is a better-connected midsurface. It retains all the necessary features adequately 'representing' the gross shape.

Effectiveness of **Smarf** with **10%** threshold, based on the criterion defined by Eqn. 1 is:

Entities	**Original**	**Phase-I**	**Phase-II**
Faces	833	715	522
Suppressed features		17	48

$$pR = \left(1 - \frac{522}{833}\right) X\ 100$$

$$= \mathbf{37\%}$$

The result demonstrates that even after reduction of 37% of the faces, the defeatured model retains the overall gross shape with which a well-connected midsurface can be computed.

Conclusion:

This work proposes two novel algorithms for defeaturing sheet metal CAD models that can be conveniently used for downstream application of generating a well-connected midsurface. With the first algorithm, each candidate sheet metal feature is suppressed based its sheet metal characteristics. The second algorithm leverages the size of the remnant volumes for deciding the suppressibility. Uniqueness of this approach in comparison with past approaches [5–7]:

- De-featuring rules applied are specific to the sheet metal domain.
- De-featuring rules based on geometric reasoning use the remnant (and not full feature) volume.
- Only selective de-featuring of the negative features.

A real life example shown in the "Results" section demonstrates the efficacy of the proposed algorithms with which the gross shape is successfully retained even after considerable defeaturing which is the key for generating a well-connected, good quality midsurface.

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