# Towards the fitting of parametric 2D sketches and 3D CAD models to point clouds of digitized assemblies for Reverse Engineering

Ghazanfar Ali SHAH[1,2], Franca GIANNINI[2], Marina MONTI[2], Arnaud POLETTE[1], Jean-Philippe PERNOT[1]

[1]Arts et Métiers, LISPEN EA 7515, HeSam, Aix-en-Provence, France
[2]Istituto di Matematica Applicata e Tecnologie Informatiche "Enrico Magenes", CNR, Genova, Italy

**Abstract**

*Following commonly used reverse engineering techniques, it is very difficult to reconstruct editable CAD parts or assemblies that can later be used and modified in the Product Development Process (PDP). Traditional methods follow a sequential time-consuming patch-by-patch reconstruction strategy with cumbersome procedures in which designers usually have to face many issues (e.g. decomposition in patches, trimming and connection of the patches), and generally producing "dead" models that cannot be later modified as needed. This paper describes a new reverse engineering technique that allows fitting of parametric CAD parts or an assembly to a reference point cloud to be reconstructed. The proposed fitting method can also be applied to 2D configurations to adapt a parametric 2D sketch to a 2D point cloud section. The idea is to use a parametric CAD model or a parametric 2D sketch in an optimization algorithm allowing their perfect fitting into the point cloud of a scanned mechanical assembly for efficient reconstruction of good quality CAD models. Some well-known algorithms like ICP are also used to derive the orientation and position of pre-arranged CAD model or 2D sketch throughout the fitting process. Both global and local fittings are possible. The consistency of the CAD models is ensured by a modeler which updates the CAD models or 2D sketch according to the iterative dimensional modifications. The evaluation of the proposed approach is performed using as-scanned virtually generated point cloud.*

**CCS Concepts**

• ***Keywords*** → *Shape modeling; Shape reconstruction; Engineering; Computer-aided-design;*

## 1. Introduction

Today, RE turns out to be of primary interest for digital shape creation also for its use in the scope of the fourth industrial revolution, commonly known as Industry 4.0 [LU17]. In this context, not only the description of the object outer skin is important but also the RE of the parametrized geometric model is crucial for the effective exploitation and manipulation of the reconstructed model. Currently engineers have to face many issues: preprocessing of data, segmentation of point clouds, decomposition in multiple patches, fitting of primitives, trimming and stitching of the resulting surfaces. CAD models do not provide editable features trees to easily modify them. Few researchers have addressed the challenging problem of reconstructing or up dating parameterized CAD models that could then be edited and optimized in the downstream stages of the PDP.

The proposed fitting approach makes use of an optimization algorithm to find out the best values of the CAD models' dimensional parameters that minimize the deviation between the point cloud and the CAD models to be fitted. Both global and local fitting is possible. During the optimization process, the orientation and positioning of the CAD parts is driven by an ICP algorithm applied each time the dimensional parameters are modified [BM92].

## 2. Methodology

The proposed approach is composed of several modules, which act on both the point cloud and template CAD model, as it is shown in the poster. The process is not fully automatized, but it assumes some initialization actions from the user. In the initial stage of the process, the user selects a CAD model from a database of parts/assemblies to be fitted in the point cloud. One assumption is made here that the chosen CAD models are parametrized and contain the internal constraints (e.g. equations linking the parameters of the part, constraints between geometric entities as for instance perpendicularity and parallelism). Moreover, by default, all the model parameters are to be considered as variables $x_k^0$ of the fitting process. Once the model selected, the user prearranges the parts within the point cloud; this initializes the values $x_k$ of all the variables. At this stage, the optimization loop, which is the core of this proposed approach, is activated. It is based on an optimization algorithm which exploits a meta-heuristic, namely the Simulated Annealing technique in the present case, which iteratively modifies the parameters of the CAD models until they perfectly fit the point cloud according to a stop criterion. For a given CAD model $M_i$, the objective of this loop is to find out the optimal values.of the parameters $x_{j,k}$ of the parameters group $G_j$ so that the correspond-





DOI: 10.2312/egp.20191044

ing CAD model best fits the cropped point cloud $PC_i$ (local fitting). This can be formulated as a minimization problem:

$$\min_{x_{j,k} \in \mathcal{D}_{j,k}, k \in [1..N_{pj}]} E_{i,j}(x_{j,1}, ..., x_{j,N_{pj}}) = \mathrm{d}(\mathcal{M}_i, \mathrm{PC}_i) \qquad (1)$$

where $x_{j,k}$ are the variables and $D_{j,k}$ their definition domain, $M_i$ is the CAD model to be fitted in the cropped point cloud $PC_i$ and $E_{i,j}$ is the energy function characterizing this deviation. Three groups of parameters can be defined ($j \in [1..3]$): structural features, detail features and skin features. The orientation and position of the CAD models with respect to the point cloud are handled by the ICP algorithm. During the successive optimization loops, $M_i$ is updated by the CAD modeler using the generation function g, which incorporates built-in constraints (e.g. symmetries, relationships) which are not directly accessible in the optimization loop but can be satisfied from the building tree. The optimization stops as soon as the optimal parameters values have been found. Both local and global fitting are possible. In case of local fitting, the point cloud is segmented to obtain the desired set of points to perform fitting. Due to space limitation segmentation step is not detailed. Similarly, the approach allows the fitting of 2D sketches to 2D point cloud sections.

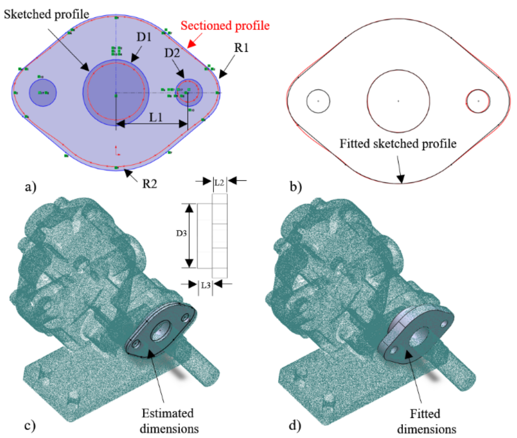


**Figure 1:** *Roughly sketched 2D profile around the sectioned profile (a), fitted 2D sketch (b), estimated dimensions of 3D features before optimization (c), locally fitted CAD model of a gland.*

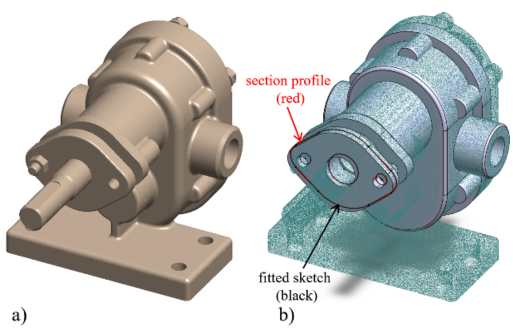


**Figure 2:** *As-scanned digitized mechanical parts assembly (a), locally fitted parameterized CAD models of a gland and a case (b).*

## 3. Results

To experiment and validate the proposed fitting strategy, the point cloud can come from a data acquisition device like a laser scanner or it can make use of the work of Montlahuc et al. [MSPP19], that bypasses the scanning of a real-life mechanical assembly and generates point clouds with all the possible defects (e.g. noises, misalignment, hidden points). Several examples have been tested for both global and local fitting of CAD parts and 2D sketches. Fig. 1 illustrates the fitting of a gland in the point cloud of a pump assembly, when no parameterized CAD model is available. In this case, fitting of 2D sketches followed by 3D part fitting is preferred. To retrieve the outer shape of the gland, a section plane has been used to obtain a section profile from the point cloud. This profile has been used as reference profile for the user to draw a parametric sketch to be fitted through optimization (Fig. 1.a). The parametric sketched profile is controlled by 5 parameters ($N_p$= 5): the holes diameters $D_1$ and $D_2$, the arcs radii $R_1$ and $R_2$ and the distance $L_1$ between the small hole and the center of the profile. Fitted sketch profile is shown in Fig. 1.b. Moreover, internal constraints (e.g. symmetry, perpendicularity, holes centered on the faces) are directly handled by the CAD modeler, which keeps track of the successive updates and of the CAD model consistency step after step. Once the outer profile is retrieved, the user puts estimated values for the two extrusions, i.e. $L_2$, and $L_3$ and one diameter $D_3$ (Fig. 1.c), from which the outer shape of the gland is derived. At this stage the optimization loop is executed to get the correct values of these additional control parameters directly on the 3D model. The process stops when there is no more change in the objective function that minimizes distance between CAD part and point cloud. Figure 1.d shows the obtained fitted gland. The central case of the pump is also obtained (Fig. 2.b) by the same procedure using also assembly constraints between the recovered gland and the pump casing to be optimized. This helps in avoiding user coarse pre-alignment of pump casing to reference point cloud before starting optimization.

## 4. Conclusions

This research introduces a new RE technique to directly fit simultaneously several parameterized parts to digitalized assemblies using part and assembly constraints, so that the resulting models can directly be used in the stages of the PDP. It bypasses the traditional tedious and time-consuming patch-by-patch reverse engineering process. The method has proved its efficiency for global and local fitting. It has been tested on several configurations. The approach is modular, and each module can further be improved.

## References

[BM92] BESL P. J., MCKAY N. D.: A method for registration of 3-d shapes. *IEEE Trans. Pattern Anal. Mach. Intell 14*, 2 (1992), 239–256. 1

[LU17] LU Y.: Industry 4.0: a survey on technologies, applications and open research issues. *Journal of Industrial Information Integration 6* (2017), 1–10. 1

[MSPP19] MONTLAHUC J., SHAH G. A., POLETTE A., PERNOT J.-P.: As-scanned point clouds generation for virtual reverse engineering of cad assembly models. *Computer-Aided Design and Applications 16*, 6 (Mar. 2019), 1171–1182. 2