Title:
**A Proposal of Experimental Protocol to Assembly Scanning**

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Introduction:
Scanning standalone components has become a routine task for many people though there may be some issues regarding the selection of the scanner with regard to the dimension of the object and the accuracy of the measures. Here, the emphasis is placed on scanning mechanical assemblies. This objective requires the combination of an assembly or disassembly process interacting with scanning processes. Such a combination adds complexity to the scanning processes due to the number of components being processed and the information looked for regarding the interfaces between components.

Consequently, the purpose of the paper is to analyze various configurations occurring during the scanning process of an assembly to formalize an experimental protocol that can improve the quality and efficiency of this process.

Main idea:
The scanning process of an assembly aims at producing point clouds to reverse engineer this assembly. Here, the purpose of this process is to produce CAD models of its components forming an assembly model. However, generating the CAD model of each component, independently of each other does not appear as an efficient process because it is not going to produce a consistent assembly model, i.e., the dimensions of reverse engineered components independently of each other will not be compatible and generate contacts in the CAD assembly and there is no information about the relative position of the components. At the opposite, scanning sub-assemblies only incorporate occlusions where components are in contact with each other and this may lead to difficulties to segment the point clouds to correctly identify components. Also, interfaces between components (contact areas) may not be effective because the dimensions of each component may not end up to be globally consistent to achieve the desired contacts at the level of accuracy of a geometric modeler.

The experimental protocol is influenced by the masses, volume and shape of its components. In the present case, the mechanisms analyzed to set up the protocol are such that the masses of components range between tens of grams to a couple of kilograms and their overall volume fit into a cube of 300mm length. To be able to analyze thoroughly the scanning processes and describe the protocol, the mechanisms studied contain ten to twenty components. In order to highlight other key characteristics of the proposed experimental protocol, other mechanisms are used to focus on particular configurations not contained in the description of the example protocols.

Due to the maximal size of the example assemblies, the scanning device used is a hand-held scanner of type T-SCAN. There is no need of other scanner like a LIDAR.

A first mechanism studied is a hydraulic ball valve (see Figure 1). This simple mechanism contains 11 components. It contains several seals formed by polyamide rings (white components in Figure 1b) and several threaded areas. Among the particular features of this assembly, it can be observed that the operating lever (blue component in Figure 1a) generates intermittent contacts on the housing when the valve is either fully opened or closed.

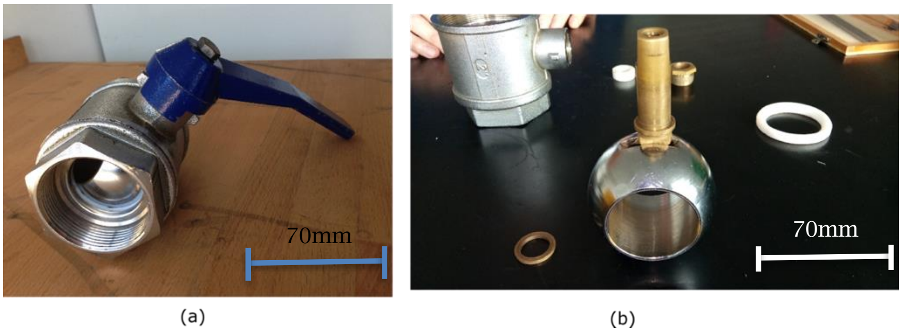


Fig. 1: (a) Hydraulic ball valve assembled and (b) major components of this valve.

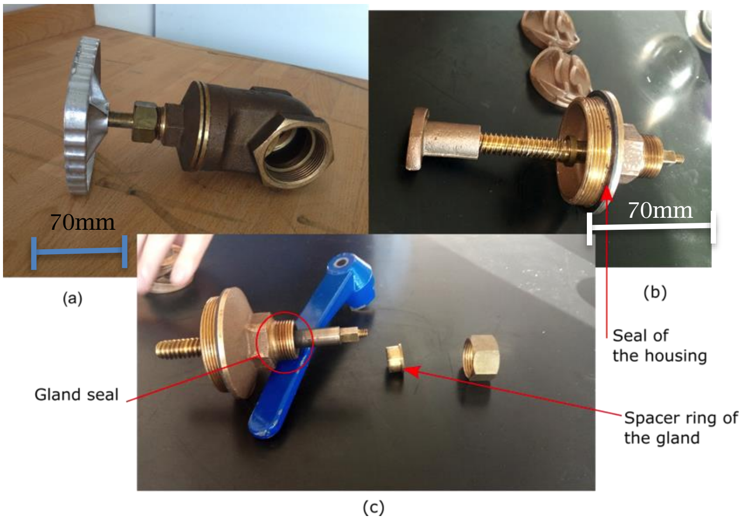


Fig. 2: (a) Hydraulic gate valve assembled and (b) major components of this valve showing the seal of the housing, (c) gland seal with its spacer ring and nut placed on the housing cap.

A second mechanism is a hydraulic gate valve (see Figure 2a). The disassembled gate is shown on Figure 2b. The hand wheel operates the gate through the shaft depicted in Figure 2c. To prevent leakage along this shaft, a gland seal is incorporated in the housing cap.

*Criteria for a scanning protocol*

Using these two assemblies as illustration, a set of criteria is analyzed and proposed that contribute to the scanning protocol.

The list and outline of criteria is as follows:

- stability positions: whether it applies to a standalone object or any sub-assembly encountered during the scanning protocol, the scanned object must stay in a stable position during scanning. Depending on the shape and center of gravity position of a component or sub-assembly, it may be necessary to resort to complementary tooling to stabilize it. This complementary equipment must contain simple primitive surfaces to ease the segmentation process separating this complementary tooling from the target component or sub-assembly. Also, it is important that

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this tooling has a small occlusion impact over their boundary for the same reason. Among the proposed solutions to these configurations, 3D printed components are analyzed,

- the level of intensity of forces needed to either insert or extract a component from the assembly. These forces depend upon the clearance between this component and the component(s) it is assembled with, i.e., it depends upon the type of linkage of the target component in the assembly.

  The force intensity is an important parameter because it indicates whether the insertion/extraction can be operated manually or not. If not, it means complementary tooling is required, e.g., a hub puller to extract a ball bearing. In this case, the volume of this tool may require moving the assembly from its previous position, which creates a point cloud with a reference frame that necessarily differs from that of the previous component removal operation. Such a configuration necessarily complicates the reverse engineering process to reconcile the point clouds of these two consecutive scans into a common reference frame.

  Whenever possible, components producing configurations with complementary tooling can be replaced by fake components avoiding specific tools. It is proposed and analyzed how these fake components can be 3D printed,

- the number of hands required to insert/extract a component. This concept is similar to the equivalent concept used in assembly simulation [1, 2, 5]. It highlights the fact that removing one component at a time is not always possible since it depends on the number of linkages one component has with its neighbors. Indeed, the number of components that must be removed at the same time indicates the number of hands needed to handle them, hence the meaning of this criterion.

  In the context of the current objective, it means the sequence of assembly/disassembly used during the scanning sequence must be performed with two hands only. This constraint is necessary to be able to extract the surfaces generating the relative position of each component with respect to its neighbors. In the case of the ball valve, Figure 3 illustrates a configuration where three hands is required.

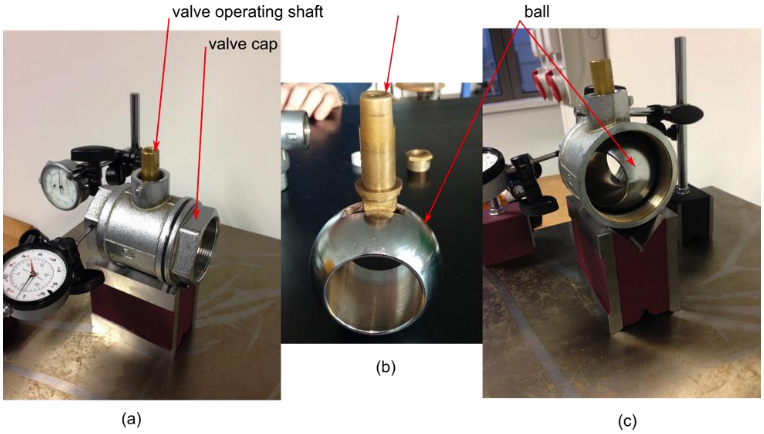
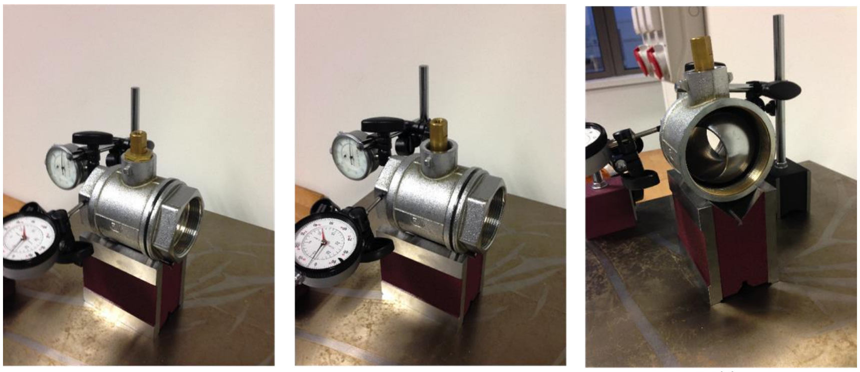



Fig. 3: An example of configuration involving three hands: the removal of the valve operating shaft. The ball valve is connected to two polyamide seal rings (see Fig. 1b) and to the valve operating shaft. Removing this shaft first requires three hands when removing the valve cap: one to hold the cap, one to hold the ball and one to hold the housing.

Other criteria, not mentioned in this abstract, refer to categories of components that can be regarded as deformable, to the morphology of components, categories of assemblies to distinguish those having permanent contacts from the ones incorporating intermittent contacts. Intermittent contacts are usually hard to characterize in CAD assembly models without appropriate kinematic description of linkages between components. Even though, the design aspects of such mechanisms have been rarely addressed [1, 2], finding these contacts in CAD assemblies still seems an open problem. Taking advantage of real assemblies to configure and scan them in key configurations is also of interest. This is addressed in the ball valve scanning protocol.

Yet another criterion focuses on the complementarity between component shapes that can be exploited in a protocol to improve the scanning process. This criterion appears when components contain concave areas or areas hardly accessible with the T-SCAN. In these configurations, the lack of points can be problematic to characterize linkage areas between components or simply surfaces areas of a component. However, if such areas appear in an assembly, these ‘concave’ areas are often related to other ones on the components that form a linkage. Typical such configurations are bore-shaft linkages where the bore surface can be hardly accessible to the T-SCAN whereas the shaft surface is convex and easily accessible and can produce the desired point clouds.

All these criteria form the basis of scanning protocols whose key features can be summarized as follows.



(a) (b) (c)

Fig. 4: Disassembling operations of the housing cap of the ball valve. (a) Removal of valve operating lever (see Figure 1a), (b) removal of the nut sealing the operating shaft, (c) removal of housing cap.

*Principles of scanning protocols*

Based on the previous criteria focusing on elementary steps of scanning protocols, the purpose of this phase is to identify key features of scanning protocols that can be used to combine efficiently the elementary steps.

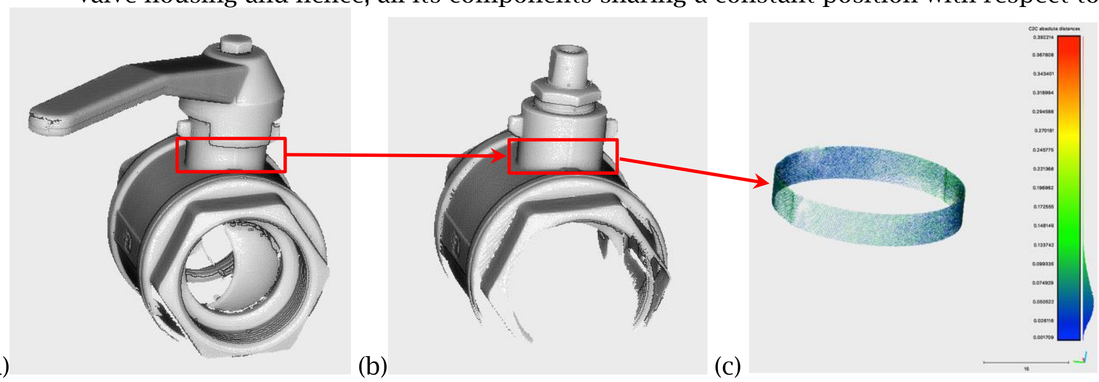
Two major aspects can be mentioned here regarding the protocols:

- taking into account the structure of an assembly. A first aspect that helps structuring an assembly holds in the distinction between standard components or components belonging to families and components that can be qualified of ‘specific’ ones. Standard components are peculiar in the sense that their standardization brings information that specific ones don’t have. The shape of these components can be described through the list of primitive surfaces defining its boundary, the geometric properties connecting these primitives, their associated symmetry properties and their dimensions. All these informations can benefit their reverse engineering process to increase its efficiency, to take into account the repetitive occurrence of these components into an assembly. If the reverse engineering algorithms lead to an user-assisted process, extracting multiple occurrences of these components can be made more efficient once one occurrence has been reverse engineered and its structure extracted to be used to identify other occurrences.

  Components belonging to families differ from standard components in the fact that their dimensions vary among successive occurrences. A definition of families of components is also proposed in [4],
- setting up common reference frames across elementary scanning steps. Considering the example of a scanning process based on disassembly process, it appears efficient to be able to make sure that the removal of a component does not alter the position of the components left. If so, this property is helpful because the successive point clouds obtained before and after this

removal are registered in the same reference frame. Consequently, there is no need to process these point clouds through ICP type algorithms.

An example of protocol incorporating this property is illustrated in Figure 4 for the ball valve when its operating lever, nut and housing cap are removed. During this process, mechanical sensors, i.e., mechanical dial gages (see Figure 4), are used to ensure the invariance of the ball valve housing and hence, all its components sharing a constant position with respect to it.



(a) (b) (c)

Fig. 10: Point clouds comparison. (a) Scan of the ball valve in the 'initial' configuration prior to the disassembly process, (b) Scan after removal of the screw and lever, (c) Distribution of distances between the common areas of the two-point clouds (a and b). The selected areas on scans (a) and (b) are used for their comparison.

Conclusion:

The proposed approach illustrates the interest in studying and analyzing scanning protocols so that they are able to produce more robust information that can be efficiently processed when reverse engineering assemblies. Criteria that can improve the scanning process at each step of a scanning protocol have been identified, analyzed and tested.

The connection between the scanning protocol and the reverse engineering algorithms is also addressed to be able to adapt these algorithms to the peculiarities of assembly processing. This is illustrated with the example in Figure 5.

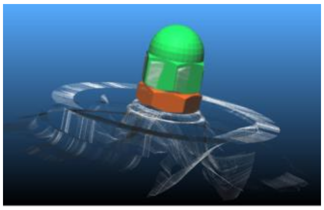


Fig. 5: An example of result extracting standard components from a point cloud.

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