Title:
Choice of CAD model Adaptation Process for Virtual Reality using Classification Techniques

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Introduction:
Virtual reality and augmented reality (V/AR) techniques are increasingly used in industry ([3], [6]) to support training, design, manufacturing, or maintenance activities. In an industrial context, these V/AR applications integrate 3D models resulting from Computer-Aided Design (CAD) models. Today the adaptation process of a CAD model for a V/AR activity is very time-consuming. The adaptation result is often of poor quality or it is poorly adapted to the V/AR activity. This is due to a several reasons, CAD and V/AR formats are not compatible; CAD models are too large for V/AR applications; the adaptation process does not meet the need for a specific V/AR activity. All of this slows down the deployment of V/AR techniques in the industry ([7], [9]).

However, many tools offer a variety of adaptation functions. An adaptation process applies a succession of these tools and functions. It is difficult to know what the best adaptation process is for a specific V/AR activity. Thus, being able to know a priori the best adaptation process will facilitate the development of V/AR applications. Therefore, the development of V/AR application will be shortened. Moreover, the quality of the final V/AR application will be improved. We propose to help the developer of the V/AR application to choose the best CAD model adaptation process. In previous work ([4], [5]), it was proposed a method to evaluate an adaptation process of a CAD model by using machine learning techniques in a different context. In this paper, we propose a new approach to predict the best adaptation process of CAD models for a specific V/AR application using techniques of classification. One challenge was to model a specific adaptation process of CAD data for each objective of V/AR application. A second challenge was to identify variables that influence the choice of adaptation process. The proposed approach will be illustrated and validated on examples of adaptation for various original CAD models and industrial V/AR applications.

Method to Choose a CAD Model Adaptation Process for V/AR using Classification techniques :
Overall approach. Our overall approach is based on four main steps (Fig. 1). First step consists in formalizing the requirements related to the V/AR activities. Then, a learning database is built by describing the requirements, the original CAD models, and the adaptation processes. Learning data are compiled in a matrix (Tab. 1) where each row represent a case that describes a known case of CAD model adaptation for a specific V/AR activity. Columns of the matrix represent vectors of variables that describe CAD
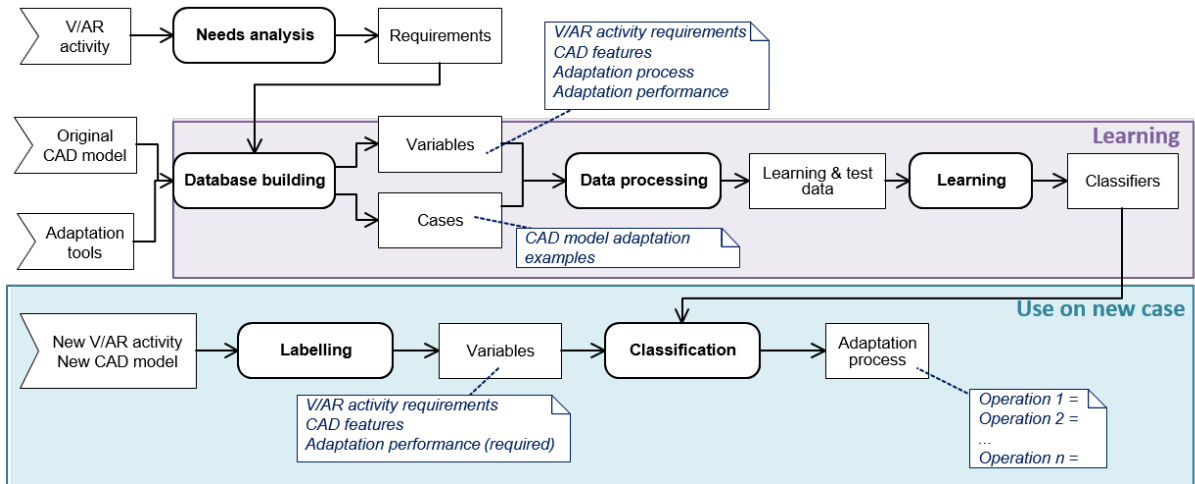
Fig. 1: Framework to choose a CAD model adaptation process for V/AR using classification techniques.

Variables:	V/AR Objectives	Quality Criteria	Satisfaction Levels	CAD Features	Adaptation Operations	Adaption Time
Values:	Qualitative	Numeric	Numeric	Numeric	Qualitative	Numeric
Known case 1:	$Xvar(1)$	$Xreq,1(1)$: $Xreq,6(1)$	$Xq,1(1)$: $Xq,6(1)$, $Xsq(1)$	$Xcad,j(1)$	$Yop,0(1)$: $Yop,5(1)$	$Ytim(1)$, $Xst(1)$
New case a:	$Xvar(a)$	$Xreq,1(a)$: $Xreq,6(a)$	$Xq,1(a)=1$: $Xq,6(a)=1$, $Xsq(a)=1$	$Xcad,j(a)$	$Yop,0(a)=?$: $Yop,5(a)=?$	$Ytim(a)=?$, $Xst(a)=1$

Table 1: Matrix for learning (known cases) and prediction (new cases) database.

models, requirements, and processes. In a third step, a set of tools for data processing is applied (e.g. normalization or reduction). This processing will allow to adapt the data to the learning algorithms. The next learning step consists in configuring classifiers for the choice of adaptation operations. In the end, for a new case (new CAD model or new V/AR activity), the configured classifiers propose a set of adaptation operations.

Need analysis. In order to meet the needs of the application user, the 3D model must be specifically adapted to the purpose of the activity. It is therefore essential to clearly identify the specifications for each type of activity. These requirements are described using four variables (Tab. 1: $Xvar$, $Xreq,i$, Xq,i and Xsq. $Xvar$ is a qualitative variable that describes the objective by specifying: i) the type of application (AR or VR), ii) the product life phase (design, manufacturing, maintenance, or service), iii) the type of activity (visualization, review, assistance, or training). $Xreq,i$ is a vector of six variables that represents the expected level of quality criteria. $Xreq,i$ takes the value of 0 if the requirement is low and 1 if it is high. Tab. 2 gives the criteria and requirements for low and high levels. Xq,i is a vector of six variables that gives the satisfaction level of the adapted 3D model for each criterion $Xreq,i$. The variable Xq,i is 0 if the result doesn't meet the criterion; Xq,i is 0.5 if the result partially meets the criterion; Xq,i is 1 if the result fully meets the criterion; Xq,i is 1.5 in case of over-quality. The global

Requirements:	Weight	Low or no requirements $(Xreq, i = 0)$	Very high requirements $(Xreq, i = 1)$
$Xreq, 1$: visualizations quality	$w1 = 1$	No visualization requirements	No latency or discomfort during visualization
$Xreq, 2$: shapes, dimensions precision	$w2 = 0.8$	The adapted and original CAD model may differ	The adapted model is completely identical to the original CAD model
$Xreq, 3$: level of details and realism	$w3 = 0.8$	A schematic representation is sufficient	The adapted model has the same rendering as the physical product
$Xreq, 4$: physics preservation	$w4 = 0.6$	No physics requirements	The adapted model behavior is the same as the physical product
$Xreq, 5$: changes facility	$w5 = 0.5$	No change is required	Real-time changes on adapted model are possible
$Xreq, 6$: collaborative work	$w6 = 0.5$	No collaborative work is required	All collaborative works are required

Table 2: Criteria of quality requirements of the 3D model for a V/AR activity.

level of satisfaction Xsq is evaluated from the weighted average of Xq, i values by factors wi.

Database building. There are three main families of adaptation tools: CAD software, adaptation software, and computer graphic software. Each tool offers one or more adaptation functions: components removing, details removing, local simplification, global simplification, or idealization. It is often necessary to use several adaptation tools simultaneously. We end up with a large number of possible processes. An adaptation process will be described by a sequence of n operations. The variables Yop, n describe operations by specifying the used tool and adaptation function. The values of variables Xsq (level of overall satisfaction) and Yst (adaptation duration satisfaction) indicate the adaptation performance. Today, choosing an adaptation process is often an arbitrary decision. The performance of the adaptation is therefore unsatisfactory. The objective of this work is to predict the output variables Yop, n and $Ytim$ (adaptation duration) with satisfactions Xsq and Yst closed to 1.

When the designer of V/AR application prepares a CAD model, he uses subjective criteria to choose his adaptation operations. These criteria are related to the size of the CAD model (e.g. area, volume), its shape (e.g. compactness, curvatures, number of faces, number of details, types of faces), and product features (e.g. number of similar components in the product, links with other components). These criteria should be formalized to be a potential variable for learning and classification. Thus, the database initially contains a set of 34 $XCAD, j$ variables, j is the index of the variable. These variables were first chosen to best characterize a CAD model, ensuring that the values of variables are not the same for two different CAD models.

Data processing. First, this step consists in applying operations of normalization and repair of missing or aberrant data. Then variables that do not influence the choice of the adaptation process are eliminated. Principal Component Analysis give projections of variables on factorial plans. These plans and correlation matrix makes it possible to identify the correlated variables with each other and their correlation coefficient. Thus, these methods allow to identify among the 34 XCAD,j variables, the most correlated variables with the Yop, n , Xsq, Xst and $Ytim$ variables. The least correlated variables will

Prediction errors :	$Yop,0$	$Yop,1$	$Yop,2$	$Yop,3$	$Yop,4$	$Yop,5$
Total:	3.20%	16.60%	9.10%	7.50%	35%	42%
Giving an over quality:	3.20%	5.80%	3.30%	4.20%	31%	23%
Reducing the quality:	0%	10.80%	5.80%	3.30%	4%	19%

Table 3: Predictions errors of SVM classifier.

be removed. This will improve the performance of the classification and facilitate future data setting.

Learning. This step consists in selecting and configuring classifiers to predict the best operation sequence for a new CAD model or a new V/AR objective. Data are partitioned into a group for learning (80% of cases) and into a group for tests (20% of cases). The total number of cases is not very high. The k-fold cross-validation method (with k=10) improves the classification performance. Various classifiers are tested and then optimized: Decision Tree, Artificial Neural Network, and Support Vector Machines. Classifiers are evaluated with the group of cases for tests using criteria of prediction errors and F1 scores. Among the prediction errors, we will distinguish the results for which the performance of the adaptation is degraded and those that lead to an over-quality.

Classification on a new case. For a new case of CAD model or V/AR activity, known variables (Tab. 1) are labeled. The global satisfaction levels $XsqL$ and Yst are set to 1. The configured classifiers predict the Yop,n and $Ytim$ output variables. The proposed adaptation operations are optimal without compromise. Therefore, the developer of the V/AR application can follow the proposed process.

Results :

We evaluated the proposed method on eight different applications of V/AR. Tools for adaptation are *CATIAV5* [2] (CAD software), *Pixyz* [8] (adaptation software), and *3DSMAX* [1] (computer graphic software). The learning database contains 600 cases of adapted CAD models. Principal component analysis and correlation matrix allowed the reduction of the $Xcad,j$ variables number from 34 to 6 variables: number of faces, compacity, box volume, ratio of volumes between part and product, ratio of areas, number of parts. These variables are not correlated with each other, and they are correctly correlated with the variables Xq,i, Xsq, Yop,n, Xst, and $Ytime$. The best classifier is a Support Vector Machines algorithm with a sigmoid kernel. The Tab. 3 shows acceptable prediction errors and high F1 scores for this classifier. The addition of new cases in the database should improve these scores.

The Fig. 2 gives examples of the use of our method for two parts and two V/AR activities. Regarding the part 1 without prediction (Fig. 2 (a)) , the designer of V/AR application re-models the part and keeps all the details as a precaution. This leads to an over quality and a waste of time. The predicted adaptation process for the objective of AR guidance (Fig. 2 (b)), consists in transforming the CAD model into a 2D surface by idealisation, keeping all the details. Lighter, the model is no longer over-quality. For the objective of VR training (Fig. 2 (c)), the predicted adaptation process consists in removing all details. The result is completely satisfactory for the intended objective and the time saving is significant. Regarding the part 2, the designer of the V/AR application simplifies the sub-assembly by first removing small details and then reducing the number of polygons. The result is unsatisfactory because the requirements are not taken into account (conservation of details like screws for AR guidance and precision of shapes for VR training). On the other hand, these requirements are well respected for models with predicted adaptation processes. In summary, for these examples, the prediction of the adaptation process provides an adaptation with a level of quality that perfectly meets the need.
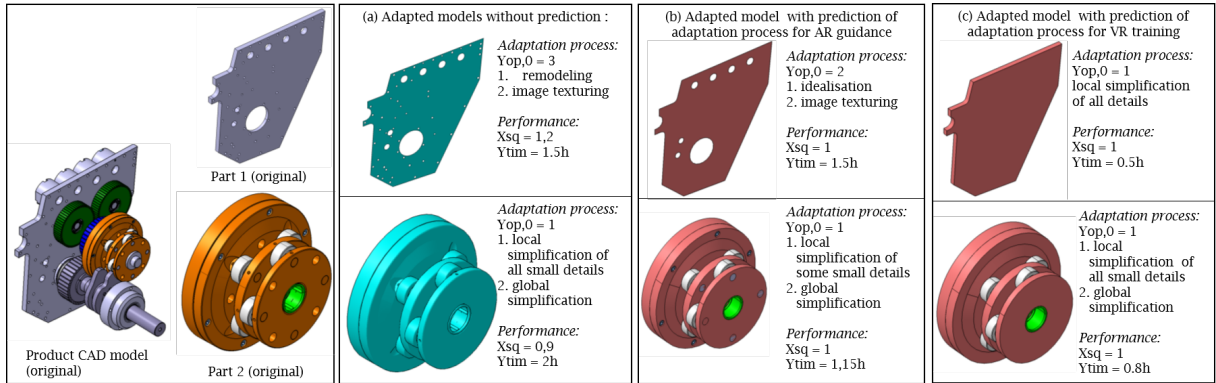
Fig. 2: Example of use on new case.(a) without prediction. (b),(c) with prediction of adaptation process.

Conclusions:

In this paper, a classification method for the choice of a CAD model adaptation process for virtual reality had been developed. While the designer relies on subjective criteria to choose the adaptation operations, our method allowed to predict the best process from selected variables. The results obtained on new cases are promising. This method helps the developer to adapt the CAD model with an ideal level of satisfaction (quality and time) by taking account the specific needs of the V/AR activity. In addition to ensuring a good quality of the adapted model, the proposed method makes it possible to know a priori the adaptation process without having to test it beforehand in the final application of V/AR. This avoids long iterations between CAD software, adaptation tools, and V/AR application creation tools. In the end, this should facilitate the deployment of V/AR techniques in the industry. With our method, the process of operations is predicted before operations are carried out. In future work, we could predict the n+1 operation in real-time by taking into account the actual result of the n operation.

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