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ECEC'2013

9TH FUTURE BUSINESS TECHNOLOGY CONFERENCE

FUBUTEC'2013

EDITED BY

Cristina Cherino

Grzegorz Cielniak

and

Patrick Dickinson

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Preface

It is our great pleasure to welcome you at Lincoln University, Lincoln United Kingdom, for the European Concurrent Engineering Conference (ECEC 2013), the FUture BUsiness TEChnology Conference (FUBUTEC 2013) and EUROMEDIA'2013, which are held from June 10th-11th, 2013, and supported by Lincoln University.

This year's event, unfortunately suffers from the general economic malaise gripping research in Europe and it is therefore below par as to the number of presentations, but luckiliy not as to the quality of the papers presented. As a result of this low number of presentations we had to merge the three events into one proceedings.

The accepted presentations for the conferences cover Risk Management, Management Techniques, Production Design Optimization and Video Applications. The presentations provide an open forum for researchers from academia and other research communities to present, discuss and exchange related ideas, results, and experiences in these areas.

For the benefit of the participants and authors, we have endeavoured also to make the event an interesting one by inviting a number of high-level speakers to expand upon their research for the general benefit of all those present.

The invited talks are by David Wortley, of Immersive Technologies Strategies, who will talk on "The Future of Serious Games and Immersive Technologies", by Prof. Kofi Appiah, of the University of Essex in Colchester, United Kingdom who will talk on "Multi-Core to Many-Core: Intel's Blunder and Gamer's Nightmare" and by Prof. Sean Lawson of Lincoln University, Lincoln, United Kingdom.

The conferences also feature a tutorial by Dr.John C.Murray of the University of Lincoln on Gesture Recognition and Control using Microsoft Kinect.

As we would also like to introduce you to research done at Lincoln University, a visit is envisaged on the afternoon of the 2nd day of the event to the Games Development Laboratory.

We would like to thank all the authors for submitting their research works within the conferences, as well as to the authors of accepted papers for their participation and presentation of the papers during this year's event.

Furthermore, we also hope you have some free time after the conferences to enjoy the beautiful city of Lincoln and its surroundings.

We look forward to meet you all again in Bruges in April 2014 for next year's edition of the conferences!

Cristina Cherino
Grzegorz Cielniak
And
Patrick Dickinson

FUBUTEC-ECEC-EUROMEDIA'2013
Conference Chairs

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SCIENTIFIC PROGRAMME

RISK MANAGEMENT

ANALYSIS OF THE SUBJECTS' ATTITUDE TOWARD RISK AND AMBIGUITY IN A FINANCIAL GAME THROUGH A BAYESIAN NETWORK

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KEYWORDS
Bayesian networks, Adverse selection, Behavioral finance, Gender, Credit Screening, Self-selection.

ABSTRACT

The purpose of this paper is the analysis of subjects' attitude toward risk and ambiguity in a financial game via a Bayesian network (BN), which have been proof to be a powerful tool in contexts of uncertainty. The paper describes the process of construction and analysis of a BN. To perform the BN analysis we consider three reasoning patterns: *evidential* reasoning, *causal* reasoning and *intercausal* reasoning. We built a BN from a data set composed of twelve variables, which were identified as relevant to this study. The structure and parameters were learnt with R language and the BN was implemented in Netica software.

INTRODUCTION

A key question in credit markets is how to disclose borrowers' private information. Banks often cannot observe ex ante failure probabilities of potential borrowers. To deal with this informational asymmetry, banks offer incentive compatible contracts (with collateral) to induce borrowers to disclose their private information. Typically, theoretical models show that private information is fully disclosed in equilibrium, since high risk and low risk borrowers self select by choosing different contracts. Low risk borrowers choose higher collateral at a lower interest rate, while high risk borrowers select contracts without collateral at a higher rate. The key is that the cost of investing in collateral is lower for low risk borrowers as they have a lower probability of failure (see (Comeig et al. 2013) for an empirical research). However, this self selection is achieved when potential borrowers are identical in every respect other than failure probability. In (Smart 2000) it is showed that the addition of the customer's degree of risk aversion can change the nature of equilibrium, and different risk classes may be pooled at a single contract in equilibrium (see also (Finkelstein and McGarry 2006) for empirical results). Specifically, risk averse low-risk borrowers may not be willing to accept higher collateral to self-select. The reason is that the collateral choice is also closely connected to the degree of risk aversion (see (Cohen and Einav 2007) and (Barseghyan et al. 2011)). The higher the risk aversion the lower the willingness to accept higher collateral to self select. Low collateral exposes individuals to a lower risk by paying a higher contract price (interest rate). The purpose of the present article is to establish the relationships between subjects' attitude towards risk and ambiguity and the financial game via a BN, then it can be used to make inference (Butz et al. 2009). BNs (Koller and Friedman, 2010) (Pearl 2000) seem to be a promising tool to discover the relationships between variables (Fuster-Parra et al. 2013), they can be considered at the intersection of Artificial Intelligence, statistics and probability and constitute a representation formalism strongly related to knowledge discovery and data mining (Heckerman 1997). BNs are a kind of probabilistic graphical models (PGMs) (Larrañaga and Moral 2011), which combine graph theory (to help the representation and resolution of complex problems) and probability theory (as a way of representing uncertainty). A PGM is defined by a graph where nodes represent random variables and arcs represent dependencies between such variables. The graphical structure captures the compositional structure of the causal relations and general aspects of all probability distributions that factorize according to that structure (Glymour 2003). A PGM is called a BN when the graph connecting its variables is a directed acyclic graph (DAG). A BN may be causal or not depending whether the arcs in the DAG represent direct causal influences or not. If the arcs represent causal influences we will talk of causal BNs (Spirtes et al. 1993). Discovering causal relationships from observational data is an important problem in empirical science (Druzdzel and Glymour 1995). The assumption that arcs represent causality in elicitation process is very useful (Buntine 1996).

In Section 2 we present a background on BN. In Section 3 we describe the method: participants, structure learning, parameters learning and the BN. In Section 4 we talk about validation and classification of the BN, particularly *lc*, *hc*, and *nc* variables classify 100% of cases under study. In Section 5 we present several reasoning patterns to analyse the BN. Finally, some conclusions are given.

BACKGROUND

A directed graph **G** is a pair (**V**, **E**), where **V** is a finite, nonempty set whose elements are called nodes (which are

the variables), and **E** is a set of ordered pairs of distinct elements of **V**. The elements of **E** are called directed edges, if (**X**,**Y**)$\in$ **E**, then there is a directed arc from **X** to **Y**, **Y** is said to be a child of **X**, and **X** is said to be a parent of **Y**, **X** is also called an ancestor of **Y**, and **Y** is called a descendent. A *path* in a directed path is a sequence of nodes $[X_1, X_2, \ldots, X_k]$ such that $(X_{i-1}, X_i) \in$ **E** for $2 \leq i \leq k$. A *trail* in a directed graph is a sequence of nodes $[X_1, X_2, \ldots, X_k]$ such that either $(X_{i-1}, X_i) \in$ **E** or $(X_i, X_{i-1}) \in$ **E** for $2 \leq i \leq k$. A directed graph **G** is called a directed acyclic graph (DAG) if it contains no cycles.

Two variables **X** and **Y** in a network are *d-separated* if, for every possible trail between **X** and **Y**, there is an intermediate variable **Z** such that either: i) the connection is serial (i.e. **X** $\longrightarrow$ **Z** $\longrightarrow$ **Y** or **X** $\longleftarrow$ **Z** $\longleftarrow$ **Y**) or diverging (i.e. **X** $\longleftarrow$ **Z** $\longrightarrow$ **Y**) and **Z** is instantiated, or ii) the connection is converging (also known as a *v-structure*, i.e. **X** $\longrightarrow$ **Z** $\longleftarrow$ **Y**) and neither **Z** nor any of **Z**'s descendants have received evidence. A *Markov blanket* of **X** in a BN (**G**,**P**) is the set of nodes consisting of **X**'s parents, **X**'s children, and other parents of **X**'s children. The *Markov blanket* has the property that d-separates **X** from all other variables in (**G**,**P**); and no subset of the *Markov blanket* has that property.

Let **P** be a joint probability distribution of the random variables in some set **V** and a DAG **G** = (**V**, **A**), then (**G**, **P**) satisfies the *local Markov condition* if for each variable $\mathbf{X}_i \in$ **V** $(1 \leq i \leq n)$, $\mathbf{X}_i$ is conditionally independent of the set of all its non-descendants given the set of all its parents. The joint probability distribution factorized as a product of several conditional distributions and denotes the dependency/independency structure by a DAG:

$$P(\mathbf{X}_1, \ldots, \mathbf{X}_n) = \prod_{i=1}^{n} P(\mathbf{X}_i \mid Pa(\mathbf{X}_i)) \qquad (1)$$

In equation (1) $Pa(\mathbf{X}_i)$ denotes the parents' nodes of $\mathbf{X}_i$), it is the main reason to obtain a multivariate distribution by BNs, this equation is called the *chain rule for BNs*. The individual factors $P(\mathbf{X}_i \mid Pa(\mathbf{X}_i))$ are called conditional probability distributions (CPD). The independencies from the graph are easily translated to the probabilistic model. The joint probability distribution of the BN requires the specification of a CPD for each variable conditioned to its parents'set. In case a (**G**, **P**) satisfies the local Markov condition, i.e. each node is conditionally independent of its non-descendants given its parents, then (**G**, **P**) is called a BN.

METHOD

Participants

The 143 subjects of the experiment were students from the University of Geneva, Switzerland (23 men, 24 women), the University of Valencia, Spain (24 men, 24 women), and the University of East Anglia, UK (24 men, 24 women). They were recruited from various courses and grades using flyers. The individuals read the instructions and we answered their questions. During the experiment, the subjects received no feedback and were not allowed to communicate with the rest of the participants. At the end of the experiment, they received their earnings (the average payment was 15 Euros). Each session lasted approximately for one hour and 15 minutes and was run at the University of Geneva, either at the laboratory of the Swiss Center for Affective Sciences or at the laboratory of the Faculty of Psychology; at the University of Valencia, at the Laboratory for Research in Experimental Economics (LINEEX); and at the Centre for Behavioral and Experimental Social Science at the University of East Anglia.

Procedure

The experiment consists on a sequence of two phases: (i) we first measure individual risk attitudes and also individual ambiguity attitudes within undergraduate students and (ii) we then offer those subjects menus of two incentive compatible contracts to study self selection. To measure attitudes toward risk and ambiguity, subjects are confronted with nine lottery pairs in 2 different conditions: risk and ambiguity. The lottery pairs follow (Blavatsky 2009) test on risk and ambiguity attitudes, based on (Holt and Laury 2002) test on risk attitudes. We use three different stimuli (cards, bars and gambles). Each lottery is presented twice to each subject in order to control for the effect side (left/right) and colors.

To study the subject's patterns of behavior towards risk in the self selection mechanism, we use five incentive compatible contract menus (with collateral) to induce subjects to disclose their private information. We follow the experimental design and menus presentation of (Bediou et al. 2013), who used the contract menus originally designed by (Capra et al. 2009). This contract design is based on the (Bester 1985) principal agent game of credit screening.

Learning the structure

The problem of discovering the causal structure increases with the number of variables (Sucar and Martínez-Arroyo 1998), (Cheng et al. 2002), e.g. for each pair of variables, **X** and **Y** there are four possible kinds of connections: **X** $\rightarrow$ **Y**, **X** $\leftarrow$ **Y**, **X** $\leftrightarrow$ **Y**, **X** **Y**. The number of distinct possible causal arrangements of n variables is $4^{(\text{number of pairs of variables})}$ (Glymour et al. 1986). With twelve variables there would be $4^{(11+10+\cdots+2+1)} = 5.444518 \times 10^{39}$ possible connections between variables. In Table 1 we can see a description of the variables of our problem.

Two approaches to structure learning could basically be considered (Daly et al. 2011): i) *search-and-score* structure learning, and ii) *constraint-based* structure learning; combination of both gives an *hybrid* learning framework. Search-and-score search algorithms assigns a number (score) to each BN structure, and then the structure model with the highest score is chosen. Constraint-based search algorithms establish a set of conditional independence analysis on the data (Margaritis 2003). Using this analysis an undirected graph could

Table 1: Description of data set variables.

variable name	description
country	Spain, Switzerland, UK.
gender	Woman, man.
hand	Laterality.
birth	Year of birth.
treatment	With or without breaking down payments.
project	High risk project, low risk project.
lc	Contract with low collateral.
hc	Contract with high collateral.
nc	Not choose any contract.
menu	Incentive compatible contract menus.
saferambup	Average point where subjects choose unambiguous option.
saferriskup	Average point where subjects choose safer option.

be generated. Taking into account additional independence test, the network is transformed into a BN. *Hybrid algorithms* combine aspects of both constraint-based and score-based algorithms, they use conditional independence test to reduce the search space and network score to find the optimal network in the reduced space.

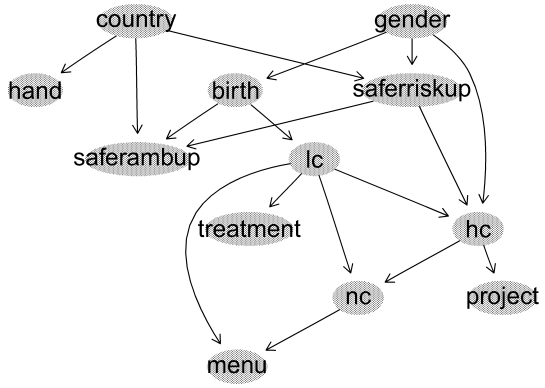


Figure 1: Pattern obtained when *mmhc* algorithm performs the search on data with prior knowledge.

In order to obtain the DAG we use the package *bnlearn* (Nagarajan et al. 2013), (Scurati 2010) of R language (R Core Team 2012). We include our prior knowledge of the system under study into the model selection process, thus variables were divided into three blocks, *background variables* = {*country*, *gender*, *hand*, *year of birth*}, *subject attitude towards risk and ambiguity* = {*saferambup*, *saferriskup*} and *financial play* = {*treatment*, *project*, *lc*, *hc*, *nc*, *menu*}. We restrict the model selection process by blacklisting arrows that point from a later to an earlier block (Hojsgaard et al. 2012). We perform the search using available learning algorithms included in *bnlearn* package; to select the learning algorithm we look for: plausibility of the model, the sparser graphs, and the score. Our final model was learnt with *max-min hill-climbing* (*mmhc*) (Tsamardinos et al. 2006), an hybrid algorithm which combines the max-min parents and children algorithm (to restrict the search space) and the hill-climbing algorithm (to find the optimal network structure in the restricted space).

Learning the parameters

In a BN the parameters are the conditional probability distributions. To obtain the parameters we perform a Dirichlet estimation using a Dirichlet distribution for each category (in Table 2 we can see a distribution probability for node *nc*).

Table 2: Table of expected values of posterior probabilities for variable *nc* conditional on combinations of its parent values, where *o* denotes otherwise and *n* denotes not playing.

lc	**hc**	**nc** $= o$	**nc** $= n$
otherwise	otherwise	0.0025	0.9975
otherwise	highWarranty	0.9995	0.0005
lowWarranty	otherwise	0.9996	0.0004
lowWarranty	highWarranty	0.5	0.5

To estimate the probability of each value of a variable (conditional on the values of the variable's parents) a prior pseudocount is added (which is 1, by default), for each configuration, the number of cases in which the variable takes that value and then dividing by the total number of cases in the prior and in the data with that configuration of parents variables. We consider the Dirichlet distribution with hyperparameters $\alpha_1, \alpha_2, \ldots, \alpha_l$ then the prior probabilities are (Neapolitan 2004):

$$p(x_1) = \frac{\alpha_1}{m} \quad p(x_2) = \frac{\alpha_2}{m} \quad \ldots \quad p(x_l) = \frac{\alpha_l}{m} \tag{2}$$

where $m = \alpha_1 + \ldots + \alpha_l$. After seeing x_1 occurs s_1 times, x_2 occurs s_2 times, ..., and x_l occurs s_k times in $n = s_1 + \ldots + s_l$ trials, the posterior probabilities are as follows:

$$\begin{aligned} P(x_1 \mid s_1 \ldots s_l) &= \frac{\alpha_1 + s_1}{m + n} \\ P(x_2 \mid s_1 \ldots s_l) &= \frac{\alpha_2 + s_2}{m + n} \\ &\vdots \\ P(x_l \mid s_1 \ldots s_l) &= \frac{\alpha_l + s_l}{m + n} \end{aligned} \tag{3}$$

Where $\alpha_1, \alpha_2, \ldots, \alpha_l$ are usually obtained by experience, that is equivalent to having seen the first outcome occurs α_1 times, the second outcome occurs α_2 times, ..., and the last outcome occurs α_l times. We consider: i) $\alpha_1 = \alpha_2 = \ldots = \alpha_l = 1$ in this case we do not have any knowledge at all concerning the relative frequency.

The Bayesian network

Although the package *bnlearn* (Scurati 2010) allows us to perform inference, in order to have a more clear graphical representation the BN was implemented in Netica software (Norsys Software Corporation 2012). The prior probabilities of the variables are computed and showed by Netica rather than showing the conditional probability distributions. Probabilities are shown as percentages. For example, in the gender node next to *woman* there is the value 46.6 which means $P(gender = woman) = .466$. This would be the prior probability for this variable, once the variables were instantiated, the conditional probabilities of the other variables given these instantiations would be shown in Netica.

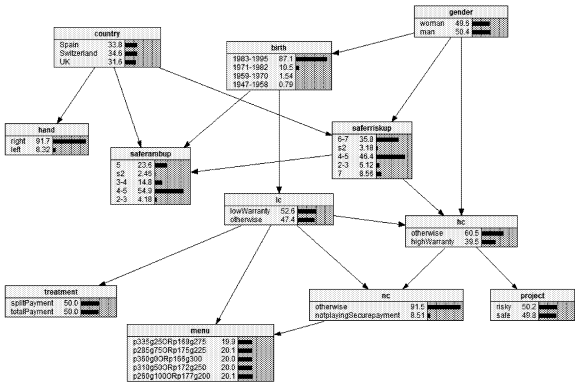


Figure 2: Bayesian network with 12 nodes implemented in Netica.

VALIDATION OF THE BN

To validate the BN we perform a 10-fold cross validation using a Gaussian Log-likelihood Loss (the negated expected log-likelihood for Gaussian BN) as a loss function, we obtained an expected loss = -17.8165. We also take into account the Receiver Operating Characteristics (ROC) also known as relative operating curves, a graphical plot of the sensitivity, or true positive rate versus false positive rate. The ROC curve falls within the quadrant 1×1 and the area under it is used as a predictive indicator of goodness. The area under curve (AUC) is defined as the probability of correctly classifying a pair of cases (positive and negative). In Table 3 we show a resume of the AUCs of different variables and the percentage correctly classified.
We also included an histogram of residuals (see Figure 3) and the relation residuals versus fitted values in Figure 4.

REASONING PATTERNS

When new information is obtained then the BN is used to calculate new probabilities (Butz et al. 2009). To find a high probability joint assignment to some subset of variables ia an important type of task (Koller and Friedman, 2010). The *most probable explanation* (also known as MAP query) is

Table 3: AUCs obtained by the ROC curves and percentage correctly classified (pcc).

variable	AUCs			pcc
	Spain	*Switzerland*	*UK*	
country	.7020	.7650	.7699	54.1353
	woman	*man*		
gender	.7208	.7207		66.7106
	right	*left*		
hand	.5752	.5763		91.7293
	1947-1958	*1959-1970*		
birth	.9926	.9325		90.3759
	1971-1982	*1983-1995*		
birth	.8640	.8254		
	risky	*safe*		
project	.6673	.6510		66.1278
	total p.	*split p.*		
treatment	.5282	.5269		53.1767
	otherwise	*l. warranty*		
lc	1.00	1.00		100
	otherwise	*h. warranty*		
hc	1.00	1.00		100
	otherwise	*n. playing*		
nc	1.00	1.00		100
	p260	*p285*	*p310*	
menu	.5652	.5175	.5252	23.0263
	p335	*p360*		
menu	.5248	.5384		
	2	*2-3*	*3-4*	
saferambup	.9840	.9227	.7053	60.9022
	4-5	*5*		
saferambup	.7107	.7554		
	2	*2-3*	*4-5*	
saferriskup	.9445	.8990	.7374	59.4925
	6-7	*7*		
saferiskup	.7204	.8747		

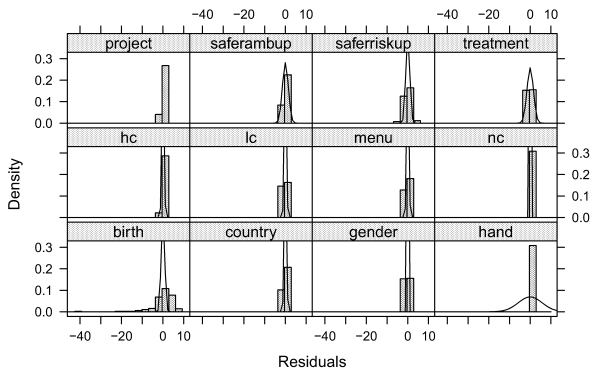


Figure 3: Histogram of residuals from the BN.

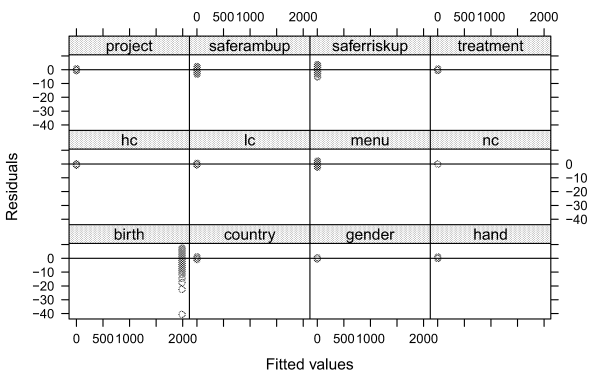


Figure 4: Residuals versus fitted.

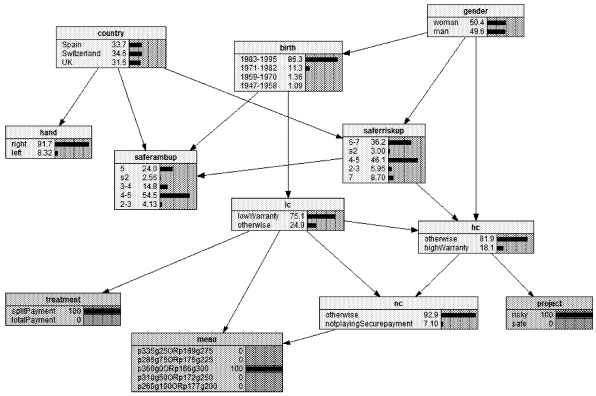


Figure 5: Maximizing low warranty with treatment = split payment, menu = p360 and project = risky.

a variant of this type of task, i.e. the most likely to all of the (non-evidence) variables. Given the evidence **E** = e, our goal is to find the most likely assignment to the variables in $\mathbf{U} = complementary(\mathbf{E})$:

$$MAP(\mathbf{U} \mid e) = argmax_u P(u, e) \tag{4}$$

We try to find the most likely assignment to a single variable in a *probability query*, that is to compute $P(\mathbf{X} \mid e)$. And we find the most likely joint assignment to **U** in a MAP query. In order to analyze the BN is necessary to know when influence flows from a node **X** to another node **Y** via a node **Z**, in such a case it we would say that the trail $\mathbf{X} \rightleftharpoons \mathbf{Z} \rightleftharpoons \mathbf{Y}$ is active.

Evidential reasoning

When we reason from effects to causes we say that these queries are instances of evidential reasoning or explanation, that is when we reason from the bottom to the top.
When we enter the following evidence: *nc* variable is instantiated to *not playing*. We observe that *lc* variable together with *hc* are the ones we highest variation on its probabilities, particularly: *low warranty* state changes from 52.6 to 2.49, in *lc* variable; and *high warranty* state from 39.5 to 2.48 in *hc* variable. It is followed by *gender*, *project* and *birth* variables; in *gender* variable *woman* state goes from 49.6 to 76.6, *man* state goes from 50.4 to 23.4; in *project* variable *risky* state goes from 50.2 to 62.6; and in *birth* variable *1983-1995* state goes from 81.7 to 92.0.
In Fig. 5 we have added the evidence where *treatment* variable takes *split payment* value,*menu* variable takes *p360g0 or p166g300* value and *project* variable takes *risky* value . We observe how *lc* variable increases its *low warranty* value from 52.6to 75.1. Another variable to be taken into account is *hc* variable, which values go from 39.5 to 18.1 in *high warranty*. The rest of variables have little changes.
When we add new evidence like *menu* variable takes *p310g50 or p172g250* value, *treatment* variable takes *total payment* value and *project* variable takes *safe* value. We observe how *hc* variable increases its *high warranty* value from 39.5 to 61.3, and *lc* variable decreases *low warranty* value from 52.6 to 34.3. The rest of variables have little changes.

Causal reasoning

When we predict from causes to effects (from top to bottom), in these queries the effects of various factors are instances of causal reasoning or prediction. When *gender* variable is instantiated to *man* and *birth* variable to *1959-1970* we observe that *saferambup* variable in label = 5 goes from 23.6 to 10.3 (in Switzerland), 8.73 (in Spain), 20 (in UK); in label = 2 goes from 2.46 to 10.3 (in Switzerland), 8.73 (in Spain), 20 (in UK); in label = 3-4 goes from 14.8 to 10.3 (in Switzerland), 8.73 (in Spain), 20 (in UK); in label = 4-5 goes from 54.9 to 58.7 (in Switzerland), 65.1 (in Spain), 20 (in UK); and in label = 2-3 goes from 4.18 to 10.3 (in Switzerland), 8.73 (in Spain), 20 (in UK). On the other hand, *saferriskup* variable in label = 6-7 goes from 35.8 to 18.2 (in Switzerland), 27.2 (in Spain), 43.3 (in UK); in label = 2 goes from 3.18 to 9.15 (in Switzerland), 4.63 (in Spain), 0.11 (in UK); in label = 4-5 goes from 46.4 to 54.4 (in Switzerland), 63.4 (in Spain), 34.7 (in UK); in label = 2-3 goes from 6.12 to 9.15 (in Switzerland), 0.12 (in Spain), 13.1 (in UK); and in label = 7 goes from 3.56 to 9.15 (in Switzerland), 4.63 (in Spain), 8.76 (in UK). We also observe: 1) *project* variable in state *risky* changes from 50.2 to 45.4 (in Spain and Switzerland), to 45.1 (in UK); and in state *safe* changes from 49.8 to 54.6 (in Spain and Switzerland), to 54.9 (in UK); 2) *hc* variable in state *otherwise* changes from 60.5 to 46.3 (in Spain), to 41.5 (in Switzerland and UK); and in state *high warranty* changes from 39.5 to 53.7 (in Spain), to 58.5 (in Switzerland and UK); 3) *lc* variable in state *low warranty* changes from 51.6 to 41.5 (in Spain, Switzerland and UK); and in state *otherwise* changes from 47.4 to 58.5 (in Spain, Switzerland and UK) (see Figure 6).
We consider the period 1971-1982 and we study variations taken into account the gender. When *gender* variable is in-

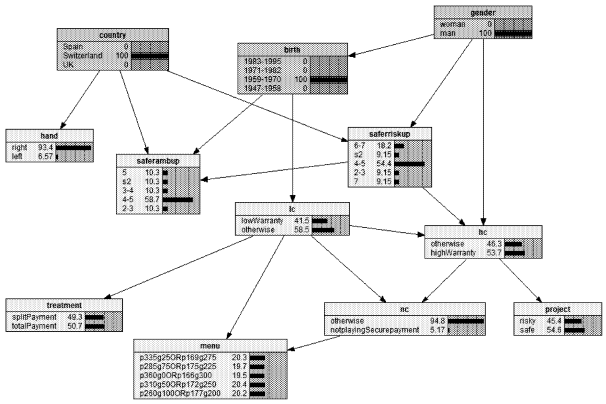


Figure 6: Maximizing *otherwise* state in nc variable.

stantiated to *man* and *birth* variable to *1971-1982* we observe that *saferambup* variable in label = 5 goes from 23.6 to 27.9 (in Switzerland), 84.4 (in Spain), 29.9 (in UK); in label = 2 goes from 2.46 to 20.6 (in Switzerland), 3.89 (in Spain), 9.52 (in UK); in label = 3-4 goes from 14.8 to 19.9 (in Switzerland), 3.89 (in Spain), 9.52 (in UK); in label = 4-5 goes from 54.9 to 28.7 (in Switzerland), 3.89 (in Spain), 41.5 (in UK); and in label = 2-3 goes from 4.18 to 2.87 (in Switzerland), 3.89 (in Spain), 9.52 (in UK). On the other hand, *saferriskup* variable in label = 6-7 goes from 35.8 to 18.2 (in Switzerland), 27.2 (in Spain), 43.3 (in UK); in label = 2 goes from 3.18 to 9.15 (in Switzerland), 4.63 (in Spain), 0.11 (in UK); in label = 4-5 goes from 46.4 to 54.4 (in Switzerland), 63.4 (in Spain), 34.7 (in UK); in label = 2-3 goes from 6.12 to 9.15 (in Switzerland), 0.12 (in Spain), 13.1 (in UK); and in label = 7 goes from 3.56 to 9.15 (in Switzerland), 4.63 (in Spain), 8.76 (in UK). We also observe: 1) *project* variable in state *risky* changes from 50.2 to 51.3 (in Spain and Switzerland), to 51.1 (in UK); and in state *safe* changes from 49.8 to 48.7 (in Spain and Switzerland), to 48.9 (in UK); 2) *hc* variable in state *otherwise* changes from 60.5 to 63.8 (in Spain and Switzerland), to 63.3 (in UK); and in state *high warranty* changes from 39.5 to 36.2 (in Spain and Switzerland), to 36.7 (UK); 3) *lc* variable in state *low warranty* changes from 52.6 to 60.7 (in Spain, Switzerland and UK); and in state *otherwise* changes from 47.4 to 39.3 (in Spain, Switzerland and UK).

Now we consider the case where gender is woman. When *gender* variable is instantiated to *woman* and *birth* variable to *1971-1982* we observe that *saferambup* variable in label = 5 goes from 23.6 to 47.6 (in Switzerland), 78.6 (in Spain), 31.4 (in UK); in label = 2 goes from 2.46 to 20.2 (in Switzerland), 5.35 (in Spain), 9.24 (in UK); in label = 3-4 goes from 14.8 to 10.8 (in Switzerland), 5.35 (in Spain), 9.24 (in UK); in label = 4-5 goes from 54.9 to 20.3 (in Switzerland), 5.35 (in Spain), 40.9 (in UK); and in label = 2-3 goes from 4.18 to 5.35 (in Switzerland), 5.35 (in Spain), 9.24 (in UK). On the other hand, *saferriskup* variable in label = 6-7 goes from 39.0 to 41.5 (in Switzerland), 39.0 (in Spain), 47.2 (in UK); in label = 2 goes from 3.18 to 0.10 (in Switzerland), 4.43 (in Spain), 0.10 (in UK); in label = 4-5 goes from 46.4 to 58.1 (in Switzerland), 43.3 (in Spain), 21.1 (in UK); in label = 2-3 goes from 6.12 to 0.10 (in Switzerland), 4.43 (in Spain), 10.6 (in UK); and in label = 7 goes from 3.56 to 0.10 (in Switzerland), 8.76 (in Spain), 21.1 (in UK). We also observe: 1) *project* variable in state *risky* changes from 50.2 to 53.2 (in Spain, Switzerland, UK); and in state *safe* changes from 49.8 to 46.8 (in Spain and Switzerland, UK); 2) *hc* variable in state *otherwise* changes from 60.5 to 69.4 (in Spain), 70.8 (in Switzerland) and to 71.9 (in UK); and in state *high warranty* changes from 39.5 to 30.6 (in Spain), to 29.2 (Switzerland), to 28.1 (UK); 3) *lc* variable in state *low warranty* changes from 52.6 to 60.7 (in Spain, Switzerland and UK); and in state *otherwise* changes from 47.4 to 39.3 (in Spain, Switzerland and UK). The rest of variables have little variation.

Intercausal reasoning

When different causes of the same effect can interact we called it intercausal reasoning. This way of reasoning constitutes a very common pattern in human reasoning.

When *saferambup* = 2-3 and *saferrisk* = 2 we observe that *hc* variable changes it *highwarranty* state from 39.5 to 54.3; *nc* variable changes it *not playing secure payment* state from 8.51 to 11.6; *project* variable changes it *risky* state from 50.2 to 45.2.

Under this situation we add more evidence *gender* variable is instantiated to *woman* value, we observe that *hc* variable increases it *highwarranty* state to 72.9; *nc* variable increases it *not playing secure payment* state to 14.2; *project* variable decreases it *risky* to 39.0, even down it initial value; *country* variable increases it *Spain* state to 98.8 from an initial value of 33.8; *birth* variable increases it *1983-1995* state to 96.5.

If we consider now the case where *gender* variable is instantiated to *man* value, we observe that *hc* variable increases it *highwarranty* state to 61.1, but it is lower than in case *gender* = woman; *nc* variable decreases it *not playing secure payment* state to 9.42, slightly higwer than the initial probability; *project* variable increases it *risky* to 50.4, similar to initial value; *country* variable increases it *Spain* state to 81.7 from an initial value of 33.8, but it is lower than in the case *gender* = woman ; *birth* variable decreases it *1983-1995* state to 79.3, even lower than when *gender* = woman.

We also study more cases, for instance when we instantiate *birth* = 1983-1995, *gender* = woman, *saferrisk* = 2, *saferambup* = 2-3, *treatment* = total payment, *project* = safe, *menu* = 310g50 or p172g250, we obtain *hc* variable increases it *highwarranty* state to 86.0 from 39.5; *nc* variable increases it *not playing secure payment* state to 13.8 from 8.51; *lc* variable decreases it *low warranty* to 39.7 from 52.6.

If instead of instantiate *menu* variable we instantiate variable *nc* to *not play secure payment*, we observe *lc* variable increases it *low warranty* state to 94.8 from 39.7; *hc* variable increases it *high warranty* to 94.9 from 86.0.

When we instantiate *birth* = 1947-1958, *treatment* = split payment, *project* = risky, *menu* = 360g50 or p166g300, we

obtain *hc* variable decreases it *highwarranty* state to 1.63 from 39.5; *nc* variable decreases it *not playing secure payment* state to 1.02 from 8.51; *lc* variable increases it *low warranty* to 98.1 from 52.6 (see Figure 7).

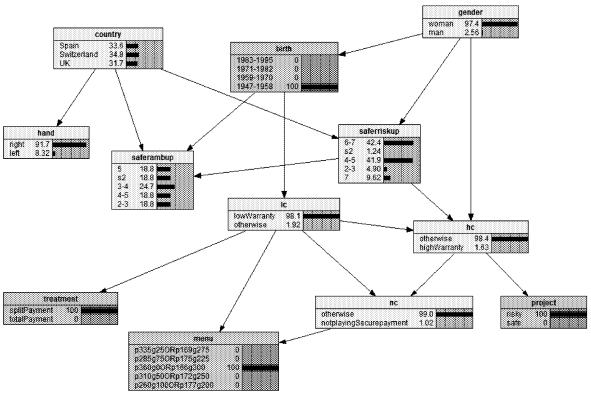


Figure 7: Maximizing *lc* variable in low warranty state and *hc* and *nc* variables in otherwise state.

CONCLUSIONS

We have chosen BNs to allow a clear graph representation of our problem, they help us to identify easily the relationships of *dependencies* and *independencies* among variables. BNs are also a graph-based structure of a joint multivariate probability distribution. BNs are a powerful tool for modeling the decision-making process under uncertainty, which combine a qualitative and quantitative representation at the same time. We have taking into account three reasoning patterns in the data set: evidential reasoning, causal reasoning and intercausal reasoning, which let us study how influence flows, i.e. when a trail is active or not according to the dependencies or conditional independencies that are derived in the graph. Through BN analysis we achieved several conclusions, among them gender differences in self selection due to differences in risk attitudes.

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FUTURE DECISION-MAKERS AND COMPLEXITY: LEARNING PROBLEM STRUCTURING THROUGH SYSTEM DYNAMICS

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KEYWORDS
System Dynamics, Complexity, Problem Structuring Methods, Problem Solving, Education

ABSTRACT

Studies on complexity suggest two sources for uncertainty. On one hand, environments constituted by immense numbers of actors interacting through (almost) infinite relationships. On the other, subtle changes recognizable only after it is too late to react. We characterize both situations as complex because of the difficulties to guarantee any links between causes and effects, and to identify effective and efficient paths for action.

This paper deals with the challenge of introducing our students, future decision-makers, to the exercise of simulating systems with complex behaviors. System Dynamics (SD) is used to illustrate the process from a problem structuring perspective. By modeling and simulating different scenarios, complex situations can be studied and analyzed. Conceding that these activities may help on improving human action, the difficulty would strive on how to teach its use as it seems difficult to be caught by students. This paper elaborates on this by proposing an approach based on looking at SD as a problem structuring method (PSM), rather than a problem solving tool. An instance of the procedure is provided from a SD course delivered to undergraduate students in a Mexican university, and criteria to evaluate its efficiency and effectiveness are discussed.

INTRODUCTION

For several years we delivered the module of System Dynamics (SD) for undergraduates at the Tecnológico de Monterrey, Mexico. Although changes in the curriculum were introduced the aim continued to be the same, to provide students with tools and concepts of SD in order to develop their abilities to make decisions in complex environments. We understand these as situations where multiple actors interact, making predictions about future collective behaviors difficult to guarantee (Waldrop 1994). We also consider complex systems those subjected to subtle changes, imperceptible to strategists and decision-makers (Senge 1992; Sterman 2000). In any case to represent and analyze these different sources for complexity are tasks that should be considered in our students' curricula in order to prepare them to conduct effective and efficient decision-making processes in the future. By effective we mean to allow testing some of our deeply held beliefs (Sterman 2002). By efficient we follow the classical understanding of being able to reduce one's future efforts by doing something in the present; the relation between the input and output within a given operation (Espejo et al 1996).

Different aspects of reality have been explored through the use of SD – e.g. systems thinking (Kauffman 1980); organizational behavior (Senge 1992); sustainability (Meadows et a, 1993), and business dynamics (Sterman 2002; Morecroft 2007; Warren 2008). In this paper, we will follow none of these roads. We will elaborate on a more general task; the fundamental ability of framing 'reality' into something less complex and more understandable and manageable, such as a model (Pidd, 2004). For Pidd models uses are two-fold: (a) to routinize decision making and (b) as supportive tools for thinking. This paper will focus in the second. Our intention is to discuss how to provide SD students, our future professionals, with a 'model for' the design and implementation of 'models about something'. The aim of this recursive task is to support reflections on our practices and, as a consequence, to provide elements for improvement. The challenge is the need to make SD "accessible to the widest range of scholars, students and policy makers" (Sterman 2002)

SIZING THE TASK

During the first session of our module we ask our students two questions: (a) What is System Dynamics? and (b) What is it useful for? The

intention is to confirm the extended confusion between two different ways of modeling reality; a 'model about something' (what it is SD?), vs. a 'model for something' (what it is SD for?). This paper shows the results of a sample of 33 students of cohorts from Tecnologico de Monterrey, campus Irapuato and Guadalajara, in 2009.

Looking at the answers from the first question "What is SD?" less than 10% are able to introduce the notions of 'model', 'system' and 'change on time', but they forget or overlook other ideas such as 'feedback' and 'delay' though. In fact, more than half of our students are unable to link SD with the field of "systems theory". Tables 1 and 2 show the responses to the two different questions.

Table 1: Answers to the question: What is System Dynamics?

Answer	Frequency
I don't know	39.4%
To observe and model a system	24.2%
Systems' flows studies	12.1%
To model systems that change through time	9.1%
Supply chain studies	9.1%
Plant distribution studies	3.0%
Application of optimization tools	3.0%
	100.0%

The absence of previous experience in SD is in itself not a problem at all. During the module we visit different aspects of the topic and provide illustrations and examples to introduce our students into the discipline. What seems worth to notice anyway is that new students do not show any understanding about challenges dealing with complex system behaviors.

Table 2: Answers to the question: What is System Dynamics for?

Answer	Frequency
I don't know	24.2%
Prediction	21.2%
Better solutions	18.2%
Better industrial processes	9.1%
To understand systems' behavior	9.1%
For the adequate bevahior of a system	6.1%
Better decision making	3.0%
Systems design	3.0%
Efficient use of resources	3.0%
For goods and services enterprises	3.0%
	100.0%

This should not be a source of alarm for us, as it does not seem to be new; however it is worth considering that linear solutions are usually incomplete as do not consider unexpected side-effects. Accordingly, this document illustrates an approach to teach SD as a problem structuring method for representing and analyzing complexity.

TEACHING AND LEARNING SD AS A PROBLEM STRUCTURING METHOD

Pre-university students seem to be trained just on solving well-defined problems. This is not enough when dealing with counterintuitive behaviors that emerge from multilinked elements (Forrester 1971/1995). In this case, a more general approach is required; one that includes notions of modeling (Senge 1992; Pidd 2004) and allows simulating something that even though is a simplified image of reality let us to learn through the building process (Sterman 2002).

Teaching approaches to reflect on complex events by means of SD modeling has been developed in several ways; from different textbooks (Forrester 1973; Sterman 2000; Morecroft 2007) to websites (System Dynamics in Education Project Road Maps, MIT). They provide educational material to recognize the main elements on which SD is based; notions of feedback, stock, flow, time delay and nonlinearity, as we said before. They also identify general behaviors helpful to model diverse situations –i.e. archetypes (Senge 1992). However, teaching SD as a computational tool pushes our students to match 'reality' to pieces of code, and forget many complex phenomena constituted by combinations of elements. Which is then our strategy? To learn by modeling "… a person must become sufficiently involved in the modeling process to internalize lessons about dynamic feedback behavior" (Forrester 1989); therefore, we induce our students to engage in a process of research. 'Engaged research' has to do with an activity that includes researchers being a constitutive part of the object of study. Rather than claiming a differentiation between observer and observed, both are intertwined in this learning process. In this context, different didactic techniques can be followed. One possibility is to define a problem to be solved (problem-based learning, PBL). A second option is to introduce a case to be studied (method of cases, MC). A third possibility is to enroll students in a project (project-oriented learning). The first two approaches are efficient, as they reduce variability and increase standardization; the latter seems more effective to capture 'real life' experiences as introduces the human factor of jointly

building models to people unfamiliar with developing simulation devices. This is the reason for our preference to follow the latter approach.

One outstanding example of these was the project of 'El Bosque de la Primavera' (The Spring Wood) conducted by our students for the Executive Directorate of this protected area. *El Bosque de la Primavera* is a protected area of 30 thousand hectares. It is considered the lung of Guadalajara (Mexico). With 5 million inhabitants, this city has no chance to lose forested areas. The students' project involved the identification of different variables that affect the viability of the forest and explored policies that may impact the forest density. Students conducted meetings with 'clients' through a process of research that involved both actors. In this sense, it was an instance of what we consider an 'engaged research'. During the development of the model information was collected and organized following general ideas from the scientific method and SD modeling language. Among the variables considered were urbanization, geothermal stations, material banks, illegal hunting, uncontrolled exploitation, excessive pasturing, fires, and motorcycling. The model outcomes surprised the 'clients'. For instance, the amount and size of forest fires were related more to the weather than to the number of visitors. Winter and not summer was the most dangerous period – i.e. the dry season in Mexico. Therefore, restrictive policies, such as reducing visitors' quotas, are not the most effective measures. Another surprising outcome was that rather than invest in reducing fires, which are in many cases related to natural causes and can even be considered healthy to forest ecosystems, it was more effective to increase the reforestation process. As a result of this project, additional work was conducted by our students and they prepared a paper for participating in a competition of the Institute of Industrial Engineers (IIE). Other projects related to different municipal issues were: pollution impact of a refinery in the city of Salamanca; water consumption in Irapuato; future education requirements in Zapopan; public transport in Guadalajara, and the deterioration of the Chapala Lake to list some of them.

We consider that previous experiences are examples of how to involve our students in environments where it is possible to learn how to capture the complexity of real situations. Conceding so, it is worth to discuss how to evaluate this approach (and others) to teach/learn SD. We advance that teaching SD as a problem structuring method provides additional effectiveness and efficiency.

CHALLENGES FOR SYSTEM DYNAMICS AS A PROBLEM STRUCTURING METHOD

In order to evaluate teaching SD as a problem structuring method, we explore the different abilities that, according to Forrester (1989), SD provides when modeling complex situations. These are (a) to organize descriptive information; (b) to retain richness of the real process; (c) to build on the experiential knowledge of managers, and to (d) reveal the variety of dynamic behaviors according to different policies.

Organizing descriptive information

In 1610 Galileo published *Sidereus Nuncius*, one of the initial examples of scientific method application. Using 'authority' to identify where to look at and classify observations as these were collected – i.e. pre-organizing his observations (Zeeuw 2001) – he proposed a model that described moons orbiting around Jupiter. Similarly, when observing complex situations we may organize observations *a priori* by means of a model build-up that is tested *a posteriori*. For instance, in management, authors such as Deming, Juran and Ishikawa propose 'quality' to observe errors and improve organizations. Others like Ackoff, Beer, Checkland or Friend use 'systems' for similar effects. This deductive way (a) let us to introduce and test what is known; (b) allows bringing new experiences to what is known, and, (c) can be used to teach how to deal with side-effects. SD has been used with these intentions also.

In SD literature, Forrester proposes the use of 'generic structures' as a way to organize what we observe. We name them 'system archetypes' (Senge 1992). Behaviors such as exponential growth, goal seeking or oscillation are simulated through accumulators ('levels'), rates of changes ('flows') and mutual interactions ('feedback'), and used to translate observations into simplified models that emulate preferred parts of their behaviors. However, to do this involves a trade-off, to limit the variety of the phenomenon under study, but at the same time to maintain the richness of what is described. Observers' judgments should be at the foundations for drawing the boundaries that define the system-in-focus; meanwhile, future usability of descriptions about complex systems requires maintaining enough richness in order to provide elements for insight.

Retaining richness of the real process

The traditional approach to deal with the difficulties of studying complexity is to select a section of reality

– i.e. a sample – to identify its characteristics, and to extend this characterization to other parts of it. Although the success of this method is unquestionable, certain limitations are involved. Different model assumptions grasp that part of the behavior of the system that makes it relevant to study. What stays and what is abandoned is at the center of this exercise, and becomes difficult for the modeler to decide. Our students spend a lot of effort trying to develop dynamic models that emulate results rather than behaviors. To them repeating the historical data series seems more important, as they consider it the best way to confirm the validity of the model. However, SD simulations are not developed to provide point prediction (Dijkum 1997), but to increase our understanding about complex behaviors. Criteria such as user's confidence (credibility), and representativeness are at the center (Dijkum 1997). This perspective suggests adding as many views and experiences as possible to increase the model capability to represent complex reality. Following this line of reasoning, Forrester (1971/1995) claims that "a model is only as good as the expertise which lies behind its formulation. A good computer model is distinguished from a poor one by the degree to which it captures the essence of a system that it represents". This values previous experiences and expertise from others to construct valid SD models.

Building on the experiential knowledge of managers

Adding others' experiences is not an easy task (Zeeuw 2001). One common mistake is to assume that it is possible to separate knowledge from action, and thus the knowledgeable actor from the influence of his own intervention. To reduce side-effects, SD modeling is used due to its capability to communicate ideas in group discussions (Forrester, 1971/1995; Dijkum 1997; Rosenhead 2009) and behave as a problem solving tool.

Another possibility to take advantage of SD communicational capabilities is to focus on conversations about sources and opportunities for improvement. This suggests looking at SD as a problem structuring method (PSM). PSMs are a family of interactive participatory methods whose purpose is to assist groups of diverse composition on tackling complex problematic situations of common interest. According to Rosenhead (2009) PSMs are model-based group decision support methods able to interactively structure and represent complex contents, and encourage participation and commitment to actions. This suggests the need of a communicative strategy. Franco (2006) proposes 'deliberation' and characterizes this form of conversation as one where:
"... participants collectively seek to reach agreement on how to carry out an action which is of concern to them. Each party exposes their preferred courses of action and priorities. These provide the grounds for discussing the possible future consequences of particular courses of action. This type of conversation may (or may not) have well-organized rules of conduct, and may involve debate, persuasion, dialogue or negotiation as part of the process" (p. 814).

But deliberation is not an independent, one-shot, event. Axelrod (1990) suggests that high inclination to collaborate is linked to the probability of future contacts. Forrester (1971/1995) proposes the use of models to increase collaboration in an ongoing deliberation. Models can be developed as tools for insight where what-if scenarios may show effects resulting from different decisions (Pidd 2004).

Revealing the variety of dynamic behaviors according to different policies

Throughout this paper we consider 'complex' those problems impossible to solve through analytical tools – 'non-technical' according to Hardin (1968). He proposed to deal with them through improving conversations. These are the core of system dynamics models, as these are constituted by statements about system structure and the policies that guide decisions (Forrester 1971/1995). Different behaviors of the system at focus are emulated through the collective selection of different variables and their interactions. These relations are identified as close-loops or feedback loops. Elements and relations can be added or eliminated until a consensus is achieved among the participants. Therefore, key objectives of SD models are collectively exploring relations between new policies and structures, and evaluating their impact in the performance. This suggests the use of SD as support strategic analysis tool that allows increasing clients' understanding and learning – 'insight generation capacity' (Dijkum 1997). This generation capacity to in-depth understanding has been recognized by others also (Forrester 1971/1995; Sterman 2002).

CONCLUSIONS

Managing 'complexity' should be included when developing future curricula. A SD modeling module in undergraduate programs may be part of other units – e.g. business strategic (Warren, 2008). The main

goal and challenge is to induce our students to reflect on complex situations. In order to recognize the impact that present actions may have on future events, reduce side-effects and increase the rate of success 'high-quality' information is required (Zeeuw 2001). Models and simulations are popular artifacts used for this endeavor (Pidd 2004). SD has proved to be useful for analyzing complex systems and their behaviors. Forrester (1971/1995) identified the use of System Dynamics (SD) to recognize counterintuitive behaviors. Sterman (2002) claimed that SD is a method to enhance learning in complex systems. Morecroft (2007) considered modeling as an effective process for learning. In fact, by introducing different strategies into relevant scenarios something can be learned (Dijkum 1997). SD models are built in terms of feedbacks, stocks, flows, time delays and nonlinearity (Sterman 2000). To learn these elements without becoming too mechanistic in an effective and efficient way is an educational challenge.

This paper proposes a way to introduce our undergraduate students to complexity and provides criteria to test if it is an effective and efficient educational approach. We propose engaging students in improving real situations, through a formal process of research where theory and practice need to be harmonized. We suggest students to be involved in the development of SD 'models about something', in such a way that at the end of this educational process some knowledge is acquired (to be effective), and is enough to avoid future errors by doing right actions in the present (to be efficient). We consider that this is possible when presenting SD as a PSM as it "(…) can organize the descriptive information, retain the richness of the real processes, build on the experiential knowledge of managers, and reveal the variety of dynamic behaviors that follow from different choices of policies" Forrester (1989). Finally, these capabilities have been initially explored; however, additional research is required to develop additional case studies in order to identify limitations and constraints to this approach.

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BIOGRAPHY

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MANAGEMENT TECHNIQUES

A Concurrent Design Approach and Model Management Support to Prevent Inconsistencies in Multidisciplinary Modelling and Simulation

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KEYWORDS
Model management, model evolution, consistency checking, concurrent design flow, co-simulation

ABSTRACT

Cyber-physical systems are multidisciplinary systems which involve different engineering disciplines in their design. Each engineering discipline tends to use its own domain-specific languages and tools to model different aspects of a system concurrently. The concurrent modelling process may introduce inconsistencies due to lack of common knowledge and communication among domain experts. Especially for co-modelling and co-simulation developments, a huge amount of models, versions of models and design alternatives may be produced, which highly increases the design space and the chance of having inconsistent models. This paper introduces a model management support and concurrent design flow to prevent inconsistencies and maintain synchronization among models. Besides the consistency checking scheme, a co-evolution graph can be generated by the model management system to visualize the concurrent development process and prevent inconsistencies. The model management system and concurrent design flow have been applied on a line following robot to show how to use this approach and its advantages.

INTRODUCTION

Concurrent Engineering (CE) is a widely used methodology in system designs and involves engineers with various opportunities for communication. Especially for model-based cyber-physical system designs, the multidisciplinary nature implies that different engineering disciplines and domain-specific models are involved. In addition, close collaboration and coordination between different domain experts are essential to the success of such developments.

In traditional CE design flows, such as the Iterative Development Method (Larman and Basili 2003) and the Spiral Model (Boehm 1986), a physical prototype of the system is required to test and evaluate the design, which increases the time-to-market and design cost. Therefore, we advocate early integration and verification of different domain models via the *co-simulation-in-the-loop* workflow, shown as grey arrows in Figure 1. Variants of models can be created, refined, and simulated through this design cycle. Prototypes can be implemented and tested after designs are verified by the co-simulation, in order to minimize the time and cost on producing intermediate prototypes.

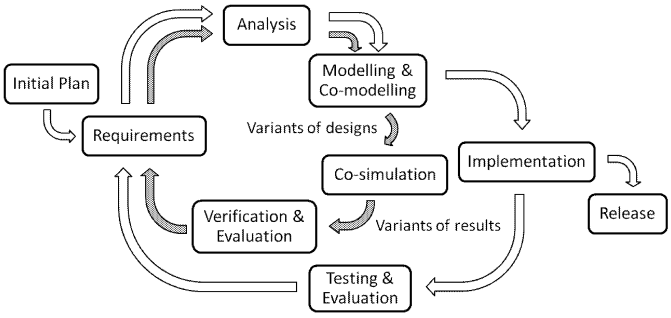


Figure 1: Iterative development flow with co-simulation in the loop

A co-simulation framework, called DESTECS[1], is used in this paper to provide a platform to co-simulate domain models in an early stage of development. With the help of DESTECS, different disciplinary models (i.e. *discrete-event (DE)* model and *continuous-time (CT)* model in a cyber-physical system), created using different domain-specific languages and tools, can be simulated and verified together before real prototypes are made.

Taking a robotic arm design as an example, experts from the control engineering and mechanical domain use the 20-sim tool[2] to model the dynamic behaviour (CT domain) of the robotic arm, while software engineers use the Overture tool[3] to implement the real-time software

[1] www.destecs.org
[2] www.20sim.com
[3] www.overturetool.org

logic (DE domain). A synchronisation scheme behind the co-simulation (Fitzgerald et al. 2012) takes care of the simultaneous execution of two tools and keeps their local simulation time synchronised.
Many versions of models and model alternatives produced at different levels of abstraction are related and have dependencies on each other. Although the DE model and CT model represent distinct aspects of the same system, overlaps on shared information still exist. Therefore, a need arises to check and ensure model consistencies during the entire co-simulation development cycle.
Unlike managing models representing different viewpoints of the same system, such as methods described in (Stumptner and Schrefl 2000), (Wang et al. 2010) and (Giese et al. 2010), finding a common formal specification like OCL (Object Constraint Language) between the DE model and CT model is difficult since they are developed and evolved simultaneously following their own semantics. Hence, inconsistencies between two domain models are mostly introduced due of the lack of common modelling knowledge and the concurrent evolution process.
Traditional approaches to the problem of concurrent working use a shared repository to which all team members have common access. Inconsistencies are usually managed through strict access control and version management, along with a common data model or schema (Nuseibeh et al. 1994).
In this paper, we propose a model management and consistency management approach, from the concurrent evolution of models point of view, to overcome the inconsistency issues in order to support the design of dependable mechatronics systems using the co-simulation technique.
The structure of this paper is as follows: we first give a brief overview of the co-simulation framework and key concepts. Based on this framework, the Model Management System (MMS) and its tool support are introduced, which describes the meta-data binding and the model evolution techniques, in order to help keep models organized and prevent inconsistencies. A case study section then follows which explains general guidelines and design flow of using the model management support. The final section gives the concluding remarks of the paper and a look forward.

BACKGROUND

The concept of a *co-model* is introduced to integrate DE and CT models and exchange data for co-simulation. As illustrated in Figure 2, a co-model consists of one DE model, one CT model and a co-simulation *contract*. All shared information between DE and CT models, such as shared variables (*svars*), shared design parameters (*sdps*) and events (*evts*), must be defined in the contract. Each domain model is connected to the contract by attaching to a *model interface* which provides a set of link statements to connect shared properties defined in the contract and in domain models, such that only shared properties are accessible to the counterpart model.

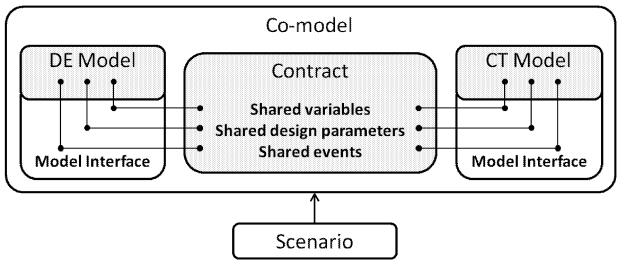


Figure 2: Basic structure of co-model and scenario-based co-simulation

For each co-simulation execution, it is possible to define a collection of *scenarios*. These scenarios can be thought of as test cases and considered as a sequence of external stimuli to the co-simulation. Each stimulus has a *time* variable associated with it, such as an event that should occur at specific points in time during the co-simulation run.
One necessary condition for a co-simulation to be consistent is that all its artefacts should not impose any contradictory aspects. This seems a natural condition, but contradictions, especially semantic level contradictions among co-simulation artefacts, are not always easy to identify. Therefore, we propose a Model Management System (MMS) to provide methods to integrate co-simulation artefacts, keep models synchronized and ensure consistency during concurrent model evolution.

MODEL MANAGEMENT SUPPORT

This section introduces the architecture of the model management system and tool support to keep co-simulation artefacts organized and synchronized. Several consistency checking schemes are proposed to prevent contradictions between domain models. A co-evolution graph is also introduced to provide a common platform for domain experts to visualize the development process, and ensure consistency during concurrent co-modelling and co-simulation processes.

System Architecture

The Model Management System (MMS) is a service-oriented system that provides a set of services to facilitate the organization and manipulation of all objects produced in a co-simulation development, including model resources and development information. The MMS architecture is depicted in Figure 3, which comprises three layers, namely the *Model Base Layer*, the *Application Layer*, and the *UI Layer*. Each layer is in-

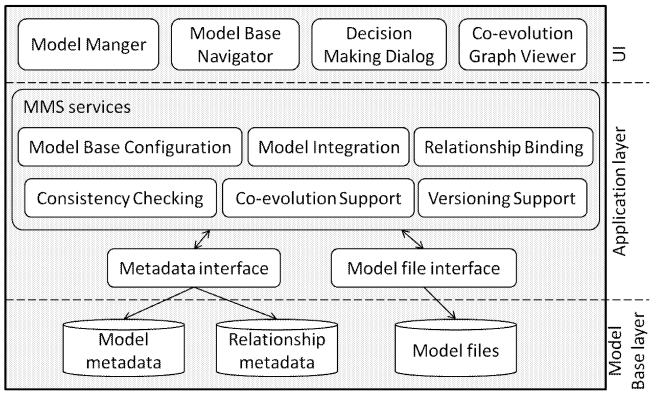


Figure 3: Model management system architecture

troduced in more detail in the following subsections.

Model Base Layer

The model base layer mainly contains three kinds of modelling information: the *Model Metadata*, *Relationship Metadata* and *Model Files*.

The *Model Files* represent the physical storage of all modelling related files of one co-simulation development, including variants of DE models, CT models, co-simulation contracts, test scenarios, simulation results, and documentations. Modellers who have the authority are able to access the model files, make changes, and reuse these model elements. This component is implemented as a distributed repository using the JGit library (i.e. a Java library of the Git revision control and source code management system), such that the entire model repository can be kept remotely and locally to prevent data loss.

The *Model Metadata* contains the meta-information of all *Model Files* and composite information about them, such as the *co-model* and *co-simulation run*, shown as (2) in Figure 4. A meta-data binding algorithm is established to ensure the consistency and synchronization between basic model files and their compositions. The meta-data binding is bidirectional; therefore, if a binding has been set, any changes on either side will reflect each other in order to keep them updated. For example, if a CT-domain expert changed a CT model which exists in a co-model element or a co-simulation run element, both these composite elements will be updated to reflect that change, and vice versa.

Since the DESTECS co-simulation framework allows modellers to explore design alternatives and design space, and also provide reasons for their design decisions, the *Relationship Metadata* defines a set of model evolution relationships that we collected from previous co-modelling and co-simulation experiences. The main purpose of having these relationships is to capture the concurrent model evolution process and provide decision making support such that inconsistencies between evolving models can be reduced.

Three types of relationships are abstracted: *design alternative*, *design step*, and *design baseline*, shown as (3) in Figure 4. In practice, it is common that more than one candidate design is made for the same development purpose in order to find optimal design solutions. We call these candidate designs *design alternatives*. Particularly, the design alternative relationship can be constructed between DE models, CT models, co-models and scenarios, respectively. While designs are evolving, the *design step relationship* represents the steps that move a design towards its final form. This may entail the addition of detail to make a model more competent for a proposed implementation. The *design baseline relationship* designates a particular design as significant in the development story, where we might expect to see a full set of scenarios, results, rationales, and documentations associated with such baselines. All these relationships are essential for keeping track of the development lifecycle and needed to generate the co-evolution graph.

Application Layer

The *Application Layer* consists of two submodules: the *MMS Services* and the *Interfaces*. The former provides higher level functions for manipulating model files and model metadata stored in the model base, as well as information that can be accessed by the UI Layer. The latter is used to facilitate communication between model management services and the model base layer.

Within the MMS services module (see Figure 3), the *Model Base Configuration*, *Model Integration*, and *Relationship Binding* are fundamental services concerning the integrated co-simulation framework. These services provide integration and binding solutions to keep individual artefacts synchronized such that a co-simulation development can be managed as a whole during its entire life-cycle.

The *Consistency Checking* service provides methods to check the syntactical consistency between two domain models and the co-simulation contract, by means of checking the `SharedProperty` object, shown as (4) in Figure 4. Model interfaces have to specify the shared properties with the exact data type, identifier name, and access level in order to execute the co-simulation. The consistency checking service creates shared property objects for all DE and CT model interfaces and contracts. For instance, when composing a co-model or a co-simulation run, the consistency checker will examine each shared object for all elements.

This service is also used for model searching and navigation purposes. When seeking potential CT domain design alternatives from the model base, the consistency checker traverses the entire model base to find consistent counter-part models which contain the same shared objects.

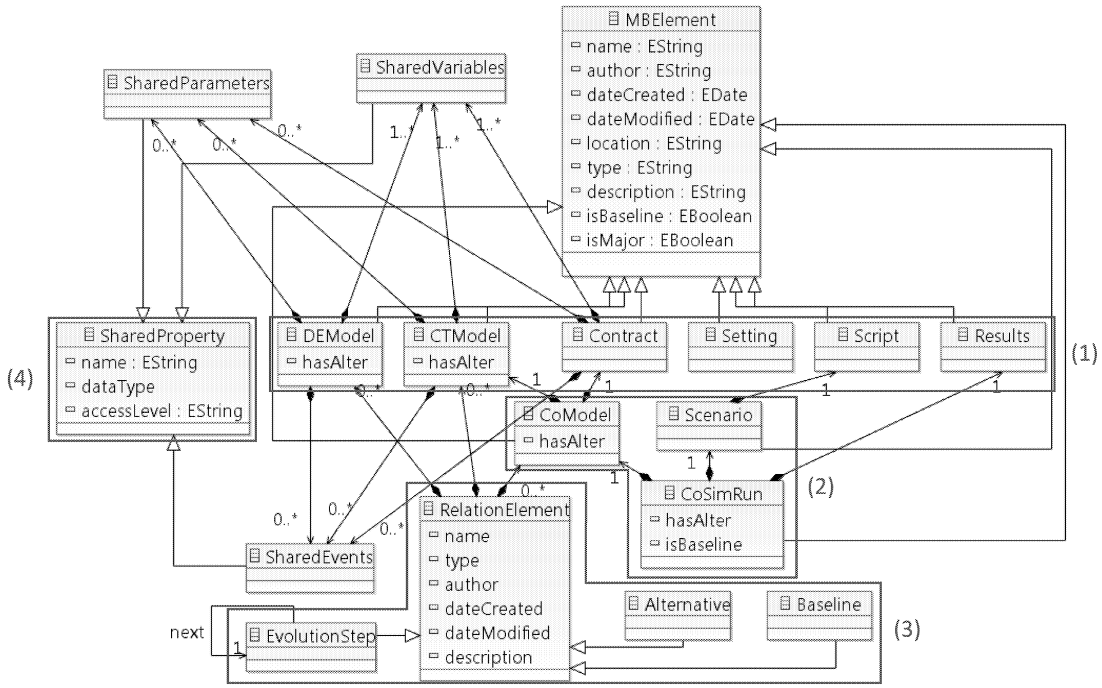


Figure 4: The model metadata and relationship metadata, where (1) basic elements, (2) composite elements, (3) relationship elements, and (4) shared property object

Together with the *Versioning Support*, the *Co-evolution Support* keeps records of all model evolution relationships and the design history of the development. With these services, modellers are able to analyse the design decisions made by other domain experts and locate possible inconsistencies that happened in the past, such that engineers can gain more common modelling knowledge and optimize their designs. A graphical visualization can be generated based on the information provided by the co-evolution support, which will be explained in the next subsection.

UI Layer

The *User Interface Layer* provides views and dialogs to facilitate the access of the model base. Consistency, dependency and synchronization issues are taken care of by the MMS services module. Modellers with valid credentials can also access multiple model bases to import and reuse models. Models that are imported from other model bases can be either *embedded* or *linked*. The former is a full-copy of the model to the current model base and can be edited locally. The latter is considered as a reference to the model; a linked model can only be read. Any changes made to the referenced model will have an impact on the target model base.

The *Co-evolution Graph Viewer* is to show the evolution process of all model base elements, from planning and structuring towards developing, design decision making, analysing, reusing, and finally discarding or approving.

The information contributed to the evolution process (EP) comes from the relationship metadata and can be defined as: $EP(o, \Delta t) = \{H, ALT, DS, B\}$. This means that the evolution process of an object o, within a time period Δt, contains the development history (H), the alternatives (ALT), design steps (DS), and baselines (B) that represent the rational and design intents behind these changes. An object can be either a domain model, a co-model or a co-simulation run, where design alternatives are only available for domain models and co-models.

Therefore, an evolution graph can be defined as a set of interconnected objects o, with relationships ALT, DS, or B over time. The objects are expressed as a collection of coloured *Nodes* and the interconnections are *Edges*, where both nodes and edges can have attributes, such as time, author, description, parents, children, etc.

Each model modification point, alternative, design step, and baseline making point is represented as a node. Depending on the type of the node, corresponding attributes are attached. Different types of edge represent different relationships between two nodes. One node can connect to multiple types of edges. For instance, a node n connects to another node m with one DS type edge, and also can connect to nodes p and q via two ALT edges.

An example graph is shown in Figure 5. Model growing over a long period of time may result in a large number of models. Therefore, the graph can be shrunk by showing fewer uninteresting models (tagged by mod-

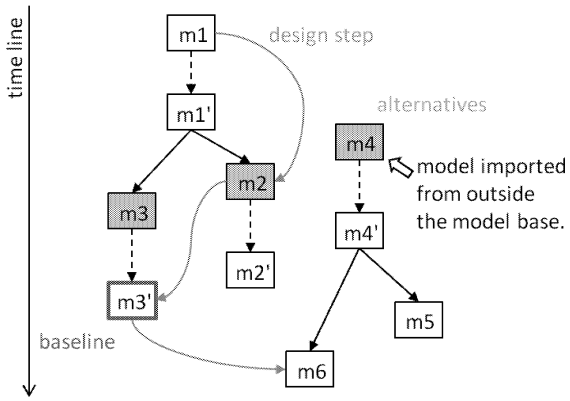


Figure 5: A conceptual example of the co-evolution graph

ellers as *minor* during development phase) and replacing the nodes by dotted lines to narrow down the information to domain experts, such that more important and useful information is shown. Modellers may expand the graph to view the entire evolution process. Searching algorithms are available to find relevant models.

EXAMPLE: LINE-FOLLOWING ROBOT

This section describes a robot design using the model management support within its design process. The entire life-cycle of the DE model, CT model and co-model, from creation to end, is tracked; this information is used to generated the (co-)evolution graph. Some design guidelines on how to prevent inconsistencies during co-simulation development are explained as well.

Problem Specification

The goal of the case study is to develop a line-following robot to track lines on the floor. A snapshot of the 3D representation of the robot is shown in Figure 6. The focus of this case study is to design such a system in the DESTECS co-simulation framework, and demonstrate the concurrent design flow using the model management system.

The target robot consists of the following features relevant to our paper: two black/white coded wheels, connected to two servo motors with built-in feedback controllers; an angular position measuring element to obtain the angular position of the wheel; infrared line-following sensors that sense contrast in the range of 0 to 255 bits. The example in Figure 6 is one alternative design of the system; two white spheres represent the two line-following sensors mounted on the front. The sphere turns black when the sensor sees a black line. More details of the design can be found in Broenink et al. (2012) and Pierce et al. (2012).

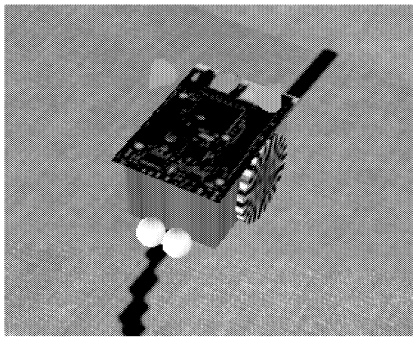


Figure 6: 3D representation of one design alternative of the robot in 20-sim tool

Iterative Design Steps

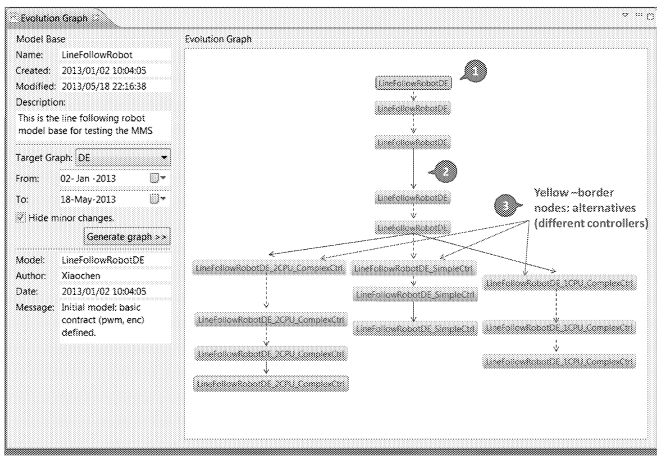
Following the iterative modelling process described in Figure 1, the iterative development process of the line-following robot is described in this section, as well as problems found during development. This section also shows the benefits of using the MMS tool and the (co-)evolution graph to help with decision making and reuse of models.

- Phase 1: Requirements and Analysis

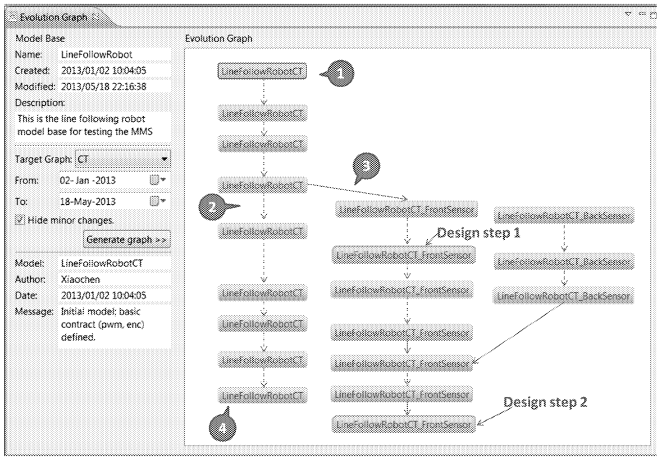
Based on the robot features described in previous section, modellers from different domains worked together and wrote a list of assumptions about the robot and environment (size and weight of the robot, sensor ranges, contact surface etc.) before defining an initial co-simulation contract. The list of assumptions is to help dealing with inconsistencies between domain models, because inconsistencies usually happen due to different interpretations of shared properties. Therefore, providing extra semantic information to all shared properties can reduce the chance of leading to inconsistent models. Such semantic information is, for example: data type, measurement unit, range of acceptable values, and the direction of positive values or reference frame.
During this phase, two major design steps are constructed which push the design from a simple robot co-model to a more complex and mature stage: Design Step 1, path following of a path known to the controller (simple, no line-following sensor involved), and Design Step 2, line-following of a path using two line-follow sensors.

- Phase 2: Co-model and Co-simulation Run Creation

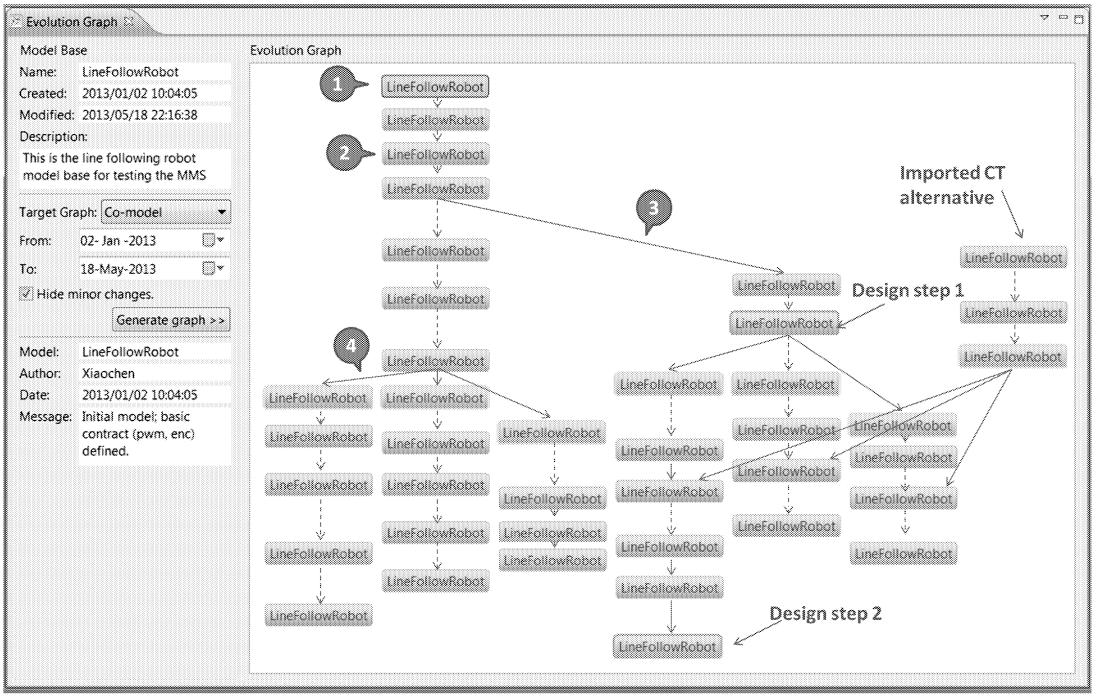
In this phase, an initial co-model towards Design Step 1 is composed and added into the model base via MMS, with mappings to each domain model and the contract. The initial points for all DE models, CT models and co-models are kept by the MMS and can be displayed in the (co-)evolution graph as the nodes ① in Figure 7(a), 7(b) and 7(c), respectively.



(a) DE model evolution graph



(b) CT model evolution graph



(c) Co-model evolution graph (i.e. co-evolution graph)

Figure 7: Evolution graphs of the line-following robot design, in which the green-border nodes represent design steps, the yellow-border nodes represent alternatives, and the yellow nodes are currently selected models (the blue texts and red arrows are not part of the tool)

Changes to each domain model and contract reflect on the mapped co-model, so the co-model also inherits the design history of its child elements, such that co-evolution is governed. Together with co-simulation settings (e.g. simulation time) and the scenario script (i.e. pre-defined run-time commands), a co-simulation run is then stored in the model base. Similar to the co-model, a co-simulation run composes a set of mappings to its children elements in the model repository. The mapping is bidirectional, so changes to the co-model or co-simulation run will also influence domain models or contracts.

- Phase 3: Co-simulation and Design Decision Making

Many design decisions are made after evaluating the co-simulation results in order to improve and refine the co-model. We hereby concluded several important decisions that influence the entire design of the robot.
During the design towards Design Step 1, some inconsistency problems occurred. The CT model became buggy when incompatible 20-sim components were added into the robot dynamic model (shown as ② in Figure 7(b)). Meanwhile, the DE modellers tested their DE controller based on the lastest working version of the CT model

(② in Figure 7(a)), and another CT modeller started adding extra functions to the working CT model while bugs were being fixed (③ in Figure 7(b) and Figure 7(c)). Due to time constraints, the buggy CT model was finally abandoned (④ in Figure 7(b)).
From Design Step 1 to 2, both contract and domain models are evolving. Adding extra sensors requires the extension of the co-simulation contract and model interfaces. At this point, the consistency checker checked both the interfaces and the contract to make sure the evolved co-model was still consistent.
A primary goal for the line-following robot is that it does not stray from the line, however the co-simulation result shows large deviations of the actual moving trajectory. Therefore, different design parameters (③ in Figure 7(a), and ④ in Figure 7(c)) are tested to find which is a better solution to keep the robot moving curve close to the line. Similar design decisions are made often in this phase of development, such as testing the influence of sensor position on the robot or the sensitivity of sensors and controller to correct the errors etc. So, modellers are recommended to frequently update their models and relationships to the model management system such that this information can be retained.

- Phase 4: Verification and Evolution Graph Evaluation

Based on development activities produced in Phase 2 and Phase 3, three evolution graphs are shown in Figure 7 for the line-following robot development. Each node in the graph indicates a model at certain time. Unimportant versions of models are hidden in the graph and use *dotted lines* to indicate that two nodes are indirectly connected. *Solid lines* are direct connections between models or model versions. The evolution graph can be generated and analysed to get an overview of the development process, and help modellers to understand each other and cooperate better.
The co-model evolution graph shown in Figure 7(c) can be considered as the co-evolution view of different types of models. Once domain models are changed, a new co-model "node" will be created to store the information of change. The co-model evolution graph is not simply overlapping the development process on two domain models, but also provides more details on the development decisions of the robot as a whole. Each node indicates which joint decisions are made during development.
These evolution graphs show all interesting design decisions and relationships between models. Generating these evolution graphs while co-modelling allows modellers to examine previous design decisions, in order to identify which designs they did wrong and why, which assumptions and decisions made by different domain modellers are not consistent, etc., such that modellers can refine their models in further development. In addition, models become easier to reuse and extend.

CONCLUDING REMARKS

In this paper, we advocate the co-simulation-in-the-loop development process using the DESTECS co-simulation framework, which highly reduces the design time and costs for cyber-physical system designs. With this framework, different domain models can be produced and verified together without implementing any physical prototypes. However, a huge amount of models and model variants may be produced during development which increases the design space and the difficulty in managing it.
Therefore, we proposed a Model Management System (MMS) and its tool support to facilitate the co-simulation development process and prevent inconsistencies. The main contributions of the work are: (1) providing a distributed model repository for collaborative modellers, (2) capturing model dependencies and keeping them synchronized during model co-evolution, (3) supporting model consistency checking when composing co-models and seeking design alternatives from the model base, (4) visualizing concurrent model evolution processes in order to locate possible inconsistencies made in the past, and (5) testing the MMS tool and iterative design flow via a case study in which possible inconsistencies are prevented.

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IMPLEMENTATION AND MANAGEMENT OF MASTER GEOMETRY IN MULTIFUNCTIONAL DESIGN ENVIRONMENT

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KEYWORDS
Master Geometry, Concurrent Engineering, Product Structure, Buffer Geometry, Master Geometry Validation Workflow.

ABSTRACT

Concurrent engineering techniques provide cooperated strategies which are totally focused on cost and time reduction of product development processes in parallel with improving quality level of final products. These improvements have to be seen as the key for success by the companies who want to be a leading force within their own field of industrial expertise. For sure, these improvements could only be obtained by continuous progress and parallel evolution of multifunctional groups involved in a design activity. This paper designates one of effective means of concurrent engineering namely Master Geometry. The role and importance of Master Geometry accordance with product development process will be explained with solid examples. On the other hand, some improper cases could be observed when a correlation is tried to be generated between Master Geometry and product structure content. These cases will be examined and potential solutions which are results of lessons learned activities will be proposed. Additionally, in order to support main topic; generic information about product structure, product lifecycle, milestones, workflow techniques and authorized roles will be given.

1- INTRODUCTION

New generation economic environment is forcing the companies to shorten lead times, to raise the quality and to lower the costs of products (Hartley 1998). It is mainly a question of processes and way of working. For conventional methods, product development processes are performed sequentially and this type of method does not answer the requirements of being a global player of challenging and competitive worldwide economy (Parsei and Sullivan 1993). If Concurrent Engineering approach is adapted and applied properly, instead of working sequentially through stages, a number of tasks will be carried out in parallel because concurrent engineering intends to provide cooperative way of working for all relevant disciplines contributing to final product, from conceptual design to marketing (Prasad 1996). Shorter product life cycles, growing product complexity, multidisciplinary way of working resulting from nature of design activities and the need for a large number of product variants have made concurrent engineering approach increasingly important for many aerospace companies (Peltonen 2000).

For all design activities, the operation has one main function; design a final product responding to all requirements. For aerospace industry, aircraft development process starts with indefinite data at aircraft level and generates concepts and ideas while proceeding towards to the final design that will be manufactured and assembled to build the aircraft. This is achieved by continual and iterative detailed design down to elementary parts. Completed aircraft has a high level complexity and could be defined as the harmony of the knowledge, experience and creativity of the multidisciplinary design and production groups. Skills of actors are closely related and there have to be continuous exchanges of information between all interested parties during product development process meaning that activities are performed within incorporate loops to refine and improve the design from top level product to elementary parts. The digital environment created and leaded by concurrent engineering provides collaborative work media where all the related departments can communicate with stakeholders.

Digital Mock-Up could be stated as one of powerful means of concurrent engineering and it is a computer simulation and 3D models of product with the capability of all the required functionality from all related disciplines involve in product development process. Master Geometry could be defined as one of auxiliary products of Digital Mock-Up. These products, especially Master Geometry, have to be definitely managed during product life cycle period by the help of product structure in order to make sure that the right data is accessible for right people at the right time with controlled access.

At following sections of this paper, in order to provide background information for the main topic firstly, definition of product structure will be given and what kind of means are being used to manage the evolution of product will be defined briefly. Additionally, detailed description of product life cycle and the relation between product structure and product life cycle will be explained. As the focus point of this paper; detailed definition of Master Geometry and its content will be given. Unsuitable cases could be faced with during product structure generation for Master Geometry will be identified and exact solutions of mentioned problems for management of Master Geometry

product structure will be proposed in order to prevent unexpected results.

2- PRODUCT STRUCTURE:

Product structure, determined from product configuration information, represents the composition, relationships and quantities of a product and its components. It could be stated that it is a common technique for representing the composition of a product. Product structures show component relationships and enable visualization of a product in relation to its higher and lower level components, from any level. Product structures are typically portrayed in a top-down manner starting with the end product and going down to the lowest level (EIA-649-B Department of Defence 2011) . In another words; product structure is a hierarchical breakdown of the product that contains all the necessary data which allows the sharing of the information with different disciplines responding to their requirements. For aerospace industry; product structure consists of different type of parts such as structural parts, systems, equipments, harness, softwares, etc. Product structure brings all different kinds of parts together in an organizational way.

With the help of product structure it is possible to access 3D model and metadata attributes of a product. It is essential to manage all involved data of a product properly with up to date versions. With this purpose, Product Life Cycle Management (PLM) tools are being used. Additionally, management of product structure and storage of all data in a single database could be provided. Different item types and different roles are defined in PLM tools in order to perform product structure activities within a protective and access controlled way. The authorized qualification of different roles gives the access of creating, approving or rejecting the digital data to each related users assigned to each role. Every role is responsible for its own item type and one role is not allowed to change the design data of another role. The design data of a product has to be approved and released in order to make it applicable for manufacturing activities. In PLM tool by the help of digital environment, the product data approving and releasing tasks are managed via workflows. Each workflow has its own rules which ensure that right tasks are done by right roles in the right sequence. It is possible to generate specific workflows for different item types.

3- PRODUCT LIFE CYCLE

Product life cycle is a generic term covering all phases of acquisition, operation, and logistics support of an item, beginning with concept definition and continuing through disposal of the item (MIL-STD-973 Military Standard 1992). From being an idea to disposal period for an aircraft, lifecycle of an aircraft could be divided to 6 different phases namely; Feasibility Phase, Concept Design Phase, Preliminary Design Phase, Detailed Design Phase, Development Phase, Serial Manufacturing and Logistics Support Phase. As the product development activity of an aircraft proceeds, it passes through a series of reviews of increasing detail. Design reviews evaluate the technical progress toward meeting specification requirements (MIL-STD-1521 Military Standard 1976). Following Figure 1 shows the design phases and design reviews related with Master Geometry generation activities.

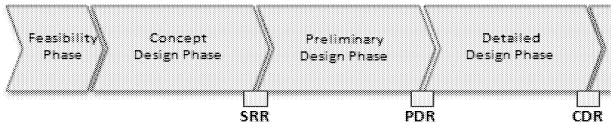


Figure 1: Design Phases and Design Reviews

Each review is tailored to ensure that the emerging design is ready to enter the next stage of development. Followings are the detailed descriptions of design review abbreviations:
SRR: System Requirements Review
PDR: Preliminary Design Review
CDR: Critical Design Review

4- MASTER GEOMETRY

Currently design activities are performed at digital environment of CAD tools and relation between separate parts or systems is provided by the help of associative physical CAD links. Consider a part which has a geometrical dependency from adjacent part on the aircraft. Somehow a geometrical references and constraints have to be defined for both parts. This situation could be defined as a common problem when the positions of parts on the aircraft and the associative information between parts have significant importance during design process. Theoretically, physical links could be generated between parts on CAD tools. However, generating CAD links from other parts or geometrical elements are not recommended, because location information of common parts and geometrical feature on the aircraft could be changed due to dynamic nature of the design activity, and they could not be considered as a reference point. In order to make sure that design activities are performed on right location of aircraft, location information of designed parts or systems on aircraft has to be identified. Designers need design parameters or geometrical indications which they can use as a reference point from aircraft geometry.

Master Geometry models provide the official source of aircraft shape, major structural and geometric information for all groups involved in the design, manufacture and in-service support of the aircraft. Master Geometry is a 3D CAD model which presents the outer geometry and the elements forming the structure of the aircraft. This geometrical composition consists of surfaces, planes, lines and points which include all necessary geometrical dependencies and constraints required for design of the air vehicle. It could be stated that Master Geometry models consist of wetted surfaces, axes, curves, reference planes and internal envelopes. The term wetted surfaces refers to the outer surfaces of the aircraft which exposure to the atmosphere. Please refer Figure 2 for an example of wetted surface.

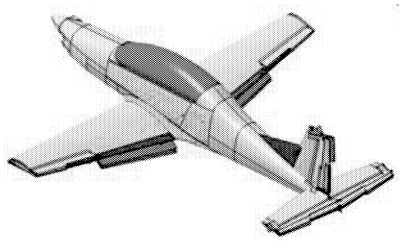


Figure 2: Wetted surface of an aircraft

Following definitions show the detailed content of Master Geometry; indications e.g. planes, coordinate systems of main structural components e.g. frames, ribs, spars, cut-outs like doors or windows and the positions of main sections (Dolezal 2007). It has to be noted that Master Geometry is not an actual part or section that is manufactured, but it is only a conceptual part, containing a sketch or general shape of the overall design and important design parameters.

The Master Geometry forms the binding basis for all geometry levels of the aircraft. It is the first geometrical reference provided to the designer. Thus, it has to be stated that structural parts could be physically linked to Master Geometry features in CAD environment, since Master Geometry models are definitely controlled references. By using Master Geometry, generating links from part to part could be prevented.

5-MASTER GEOMETRY PRODUCT STRUCTURE

For 3D design, Master Geometry models are starting points and the external aircraft geometry is the main source for Master Geometry generation. Like the other design features, additions and change requests could be also observed for Master Geometry models afterwards. Thus, management of the Master Geometry database continues for the life of the aircraft. Master Geometry is evolved through design phases and this evolution has to be managed within a protective and controlled environment. Thus, a special product structure, a special role and a special release workflow have to be defined for Master Geometry in order to provide digital environment for management of Master Geometry models and usage with up to date versions. Theoretically, it is possible to define Master Geometry Specialist role authorization, Master Geometry release workflow for authorized release cycle and Master Geometry product structure for Master Geometry models. However, several problems have been possibly observed related to product structure generation for Master Geometry, due to the nature of geometrical attributes of Master Geometry. Each problem and potential solution will be separately analyzed as following sub-titles.

5.1 Case-1:

As it is mentioned previously, all detail parts except some brackets have to be linked to Master Geometry models and Master Geometry models have to be physically linked to external aircraft geometry models at CAD environment in order to provide association between models. This means if an external geometry model is changed, associated Master Geometry model will give link update warning, so do detail parts due to updating Master Geometry models. For a basic trainer aircraft, there are more than 4000 detail parts. It could be stated that updating one detail part at CAD environment takes 1 minute. Each external geometry modification causes detail part updating workload which approximately equals to 4000 minutes. Every modification of external geometry would not have impact on detail parts. Thus, there has to be a monitoring interface between external geometry and Master Geometry models in order to prevent unnecessary updates of Master Geometry and to avoid extra updates and workloads at detail part level.

Sometimes it is possible that external aircraft geometries could be provided by aerodynamic group as a coarse model. Coarse models include draft surfaces, lack of cut out sections of the surface etc. In this case, some arrangements and fine tunings have to be performed on models which have been directly taken from external aircraft geometry and transferred to Master Geometry. These arrangements include totally CAD operations. And these all CAD operations have to be performed within Master Geometry models in order to make it applicable for design specifications. During detailed design phase, there will be excessive information in Master Geometry models such as initial information taken from aerodynamic group results of CAD operations and final geometrical features intended to use as Master Geometry. When these all information is kept within a same model, it would be impossible to use Master Geometry models properly.

Solution:

If CAD operation for fine tuning of data which has been taken from external aircraft geometry and transferred to Master Geometry is a frequent activity, there has to be a transition medium between external aircraft geometry models and Master Geometry models. In this context, Buffer Geometry model gets on the stage as a solution. Buffer Geometry functions as a transition and monitoring model between external aircraft geometry and Master Geometry. All elements taken from the external aircraft geometry are transferred to the Master Geometry after being arranged using the Buffer Geometry. If the surfaces taken from aerodynamic engineering group have been provided as a coarse model, the Buffer Geometry shall be used to make these surfaces fine to prevent excessive information in each Master Geometry model. There shall be a Buffer Geometry model for each Master Geometry model. All geometrical elements in the Master Geometry model shall only be linked to the corresponding Buffer Geometry. In this case, Master Geometry will be linked to Buffer Geometry and Buffer Geometry will also be linked to external aircraft geometry sequentially. Changes on external aircraft geometry will directly have impact on Buffer Geometry. With the help of Buffer Geometry, only effective changes could be transferred to Master Geometry models and this way of working prevents unnecessary link updates of detail parts and provides 80% time reduction for link updates at detail part level. Following Figure 3 shows the interrelation between three geometries.

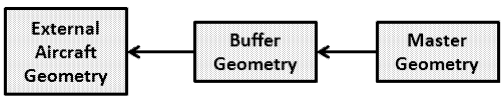


Figure 3: Function of Buffer Geometry

Direction of arrows shows the direction of associative CAD links.

5.2 Case-2:

The design data of a product has to be approved and released through workflows with revision control in order to make it applicable for stakeholders within a protective and controlled way. Same identification has to be also implemented for Master Geometry models. Consider a final product with high complexity; all parts of the product could

be linked to same Master Geometry model. When this Master Geometry model could somehow up issued from Revision-A to Revision-B due to new requirements or change requests, all items which have CAD links to this Master Geometry model also have to be up issued. Otherwise, associative CAD links between parts and Master Geometry model will become broken because associative links keeps track of the file name of Master Geometry models. Updating links and up issuing of all parts will be an enormous work load for design group.

Solution:
Giving "Released" status and issue tracking for Master Geometry Models is not recommended. Because; when you release an item through workflows, you have to keep track of the revision control of that item. In case of Master Geometry models; instead of using "Released" status, "Valid" status has to be used with a proper workflow.
Consider a change request has been received for an existing Master Geometry model. According to predefined rules of the Master Geometry Workflow; following steps will be performed sequentially: at first step; Master Geometry Specialist role informs and requests to rearrange the Master Geometry model in accordance with the design requirements. This first stage is "Request" step of the workflow and during this phase the data is frozen. At second step; Engineering Leader role confirms that the Master Geometry change is required and acceptable. This second stage is called "Assessment" step and at this step, Engineering Leader role can also reject the request. The data is set free from now on. At third step; Master Geometry Specialist role applies the changes and improvement to the design of Master Geometry model. This third stage is called "Design Check" step. At fourth step; Engineering Leader role confirms that the corrections and/or improvements are applied correctly. This fourth stage is called "Approve" step and at this step, Engineering Leader role can reject the corrections. After the "Approve" step, the Master Geometry model will be again frozen and has "Valid" status. Please refer Figure 4 for diagram of workflow.

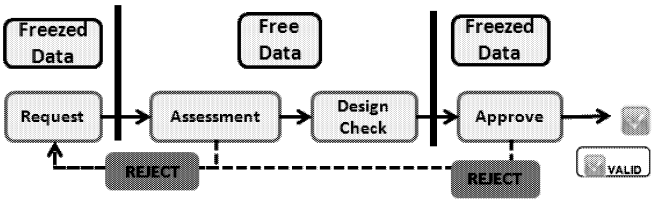


Figure 4: Workflow diagram for Master Geometry

By this way; revision control, issue tracking and link updates problems will be prevented within a protected way.

5.3 Case-3:

Master Geometry generation will start with external aircraft geometry at aircraft level and Master Geometry models will evolve in parallel with evolution of product design through design phases. At detailed design phase, structure/systems specifications definition activity is completed and component design activity starts. This means design activity becomes more detailed through elementary parts. As it is mentioned before, for 3D part design, Master Geometry models are the starting points and main references throughout development process. Thus, Master Geometry model has to have ability to answer to requirements of design activity which becomes more detailed phase by phase. For that dynamic design environment; single and at aircraft level Master Geometry could be used properly for detailed design activities, or not? For a basic trainer aircraft, Master Geometry models at aircraft level includes approximately 12000 features like lines, points, planes, surfaces etc. Using one big model for Master Geometry could be a chaos for detailed part design activities. Consider a structural designer which works on wing and totally responsible for structural parts of a definite section of the wing. When this designer tries to use Master Geometry model as a reference, he/she has to refer aircraft level model which includes all detailed geometrical information of fuselage, empennage or other major components which could be classified as out of scope according to his responsibilities. This excessive information kept in single model will causes confusion among design groups and poses as a risk for performed designs.

Solution:
Master Geometry is first created during concept design phase of the aircraft project and mainly frozen at the end of detailed design phase. The general Master Geometry shall be broken down into convenient sections, to avoid excessive information in each model and to align the Master Geometry more in line with the design and manufacture task breakdown, instead of using single model. At the end of concept design phase, it is estimated that external aircraft geometry for the product is selected among concept candidates. Accordance with the design phase which the product design activity completed properly, the content of Master Geometry model will also evolve throughout the life cycle of the aircraft. In order to provide better management of details and integration with design teams, Master Geometry shall be broken to major components, sections and/or ATA (Air Transport Association) sections sequentially. Breakdown principle is totally depends on current design phase performed. As mentioned earlier, Master Geometry design activities are mainly performed during conceptual design phase, preliminary design phase and detailed design phase. However, it is again important to note that management of master geometry database continues for the life cycle of the aircraft.
It could be stated that, breakdown of Master Geometry could be performed into 3 sub-processes. These sub-processes are composed of the same generic process but they run through different periods of time. They provide the same deliverables, but at different levels of detail depending on the milestones concerned. After the conceptual design phase Master Geometry models at aircraft level shall be generated. After preliminary design phase, Master Geometry models at aircraft level are revised and Master Geometry models at major component level are generated. At the end of detailed design phase, Master Geometry at aircraft level is again revised, the one at major component level is also revised and the one at section or ATA section level is generated. Following Figure 5 shows the breakdown of Master Geometry according to the design phases.

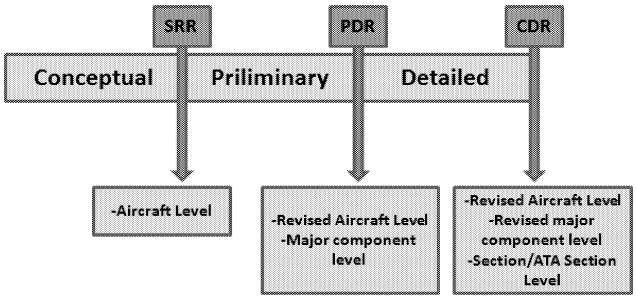


Figure 5: Breakdown of Master Geometry

At each design review gate, sequentially SRR, PDR and CDR, maturity and content of Master Geometry models have to be checked with respect to design phase deliverable to ensure that the emerging design is ready to enter the next stage of development.

6- CONCLUSION AND FUTURE WORK

This paper is aimed to present the importance of Master Geometry models on multifunctional design activities. Basically, interactions of structural design activity, system design activity and manufacturing process with Master Geometry models have been identified. Generic geometrical content of Master Geometry models has been also defined. In order to provide coherency between Master Geometry and other indications, detailed description of product structure, product life cycle and functions of product structure are given. Afterwards, three different problems could be faced with during implementation and management period of Master Geometry has been deeply analyzed and presented with supportive convenient examples. These problems could be defined in a nutshell as follows; problem number one was about filling out Master Geometry models with unnecessary geometrical information which makes Master Geometry models useless. Problem number two was about unsuitable consequences of released status of Master Geometry models and updating links workloads. And finally, problem number three was about excessive content of usage single Master Geometry models during whole product development process. After that, accordance with the results of lessons learned and know how activities potential solutions techniques have been proposed.

Future work will concentrate on issues related to the implementation and management of Space Allocation Mock-up which is a digital mock-up made of simplified 3D solid models in CAD formats. The place of Space Allocation Mock-up design within overall aircraft development will be highlighted and the link between Space Allocation Mock-up models and Master Geometry models will be presented in details.

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TOWARDS 3D CROWDSOURCING: EASING WEB3D NAVIGATION USING USER TRACES

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Crowdsourcing, Web3D, Navigation, Recommendation Views.

ABSTRACT

This paper is the first step towards easing Web3D user navigation using crowdsourcing. We collect user interactions to determine informative regions (the most popular regions) within a 3D object. We show that subsequent users can benefit from previous user navigation to improve their Web3D experience: a set of 3D poses is computed and used for recommendations to subsequent users. The recommended poses aim at simplifying the 3D navigation, that is, reducing the number of pan, zoom and rotate events the user may need to reach his/her desired regions. An experimental user study shows that our system redirects user to interesting areas quicker, with fewer interactions required.

INTRODUCTION

In recent years, many websites have made great efforts to bring 3D interfaces to users, allowing them to inspect 3D objects in real-time (3DCOFORM 2013), or explore a 3D virtual environment (SecondLife 2013, ActiveWorlds 2013). These 3D interfaces, as discussed by Chittaro and Ranon (2007) may provide the following advantages to users:

- 3D objects/scenes are more interactive and aesthetic than the traditional media such as images or video. With 3D data, the user can grasp detail information on the visualized object from any preferred viewpoint, or render with different rendering parameters (like color, wireframe or light).
- 3D interfaces allow the users to experience fun and realistic feelings. Eventually, users' emotional and social needs can be satisfied. For example, in a virtual city, the user's avatar can walk around the virtual buildings or even can communicate with other virtual pedestrians.

Providing Web3D content to users poses specific issues: 3D content may be cumbersome to apprehend, and sometimes it may take a long time for a user to identify a meaningful 3D region. Moreover, complex 3D objects often require powerful computation. Delays in rendering or time lags due to transmission can disturb users when manipulating 3D data. This leads to a demand for developing tools and systems which are capable of supporting Web3D navigation and presentation.
In this paper, we present how crowdsourcing can be used as a simple method to identify meaningful parts (called ROIs – regions of interest) of a 3D object. A set of 3D poses, called *Recommended Views* are computed based on the previous user navigation, and then suggested to subsequent users.
We organize the rest of the paper into 5 sections. We start with the background of crowdsourcing as the fundamental theory. We then have a brief review of the literature related to our work. The next section presents our proposal, including an overview of our approach, design of system architecture, methodology to collect user traces, detect ROIs and calculate recommendations. Then, we evaluate our method with an experimental user study and finally conclude the paper and give perspectives.

BACKGROUND

Crowdsourcing is an emerging research paradigm for motivating many common users to contribute their knowledge and expertise in completing the assigned tasks, traditionally performed by a designated agent (Howe 2006). From its definition, crowdsourcing has been used as a technique in which competence and expertise distributed among the members of the crowd are aggregated and exploited, as in the case of Wikipedia.
Zhao and Zhu (2012) proposed a conceptual framework for crowdsourcing, in which four main factors interact: 1) who is performing the task, 2) why people are completing the task, 3) how the task is performed, 4) what about the ownership of the result and what is being accomplished.
Figure 1 adapts their framework to our setting.
One common way to apply crowdsourcing theory in the field of multimedia is to provide a set of tools and mechanisms, allowing many common users to customize or extend the multimedia content, presentation and interaction. The convergence of the crowd is believed to produce an optimal multimedia adaptation, traditionally

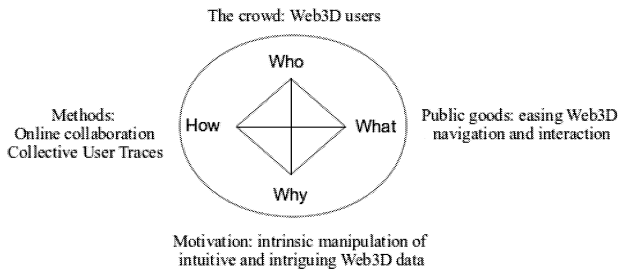


Figure 1: Crowdsourcing Model.

created by experts of the field. Two popular examples of crowdsourcing platforms are Wikipedia and Facebook. In both cases, users are volunteers to create and share their knowledge and opinions using supported tools and services. Our method belongs to this crowdsourcing for multimedia setting, targeting 3D content. We show that if a 3D object has particularly important regions, user navigation can be used to ease subsequent Web3D user experience, by helping them accessing relevant parts in less time, and with simplified interactions.

RELATED WORK

Many research efforts are devoted to improving Web3D navigation and interaction. Both Hughes et al. (2002) and Brusilovsky (2004) introduced adaptive navigation techniques (such as direct guidance, hiding, sorting or annotation) based on the analysis of the user model. The authors computed the so-called ideal viewpoints which are capable of highlighting the interesting parts of a 3D world to the user. This work allows the users to manipulate the 3D data more efficiently and effectively. However, it still shows the limitation when applied to the case of novice users for which the ideal viewpoints may not be well-defined. In our work, we rather want to learn from previous navigation of many common users, in order to identify the informative regions within a 3D object. Those determined regions are then used to compute recommendations which allow upcoming users to quickly navigate into an interesting 3D area.

Celentano and Pittarello (2004) proposed a usage-based method to support Web3D navigation. More specifically, user traces are collected and then compared with the pre-defined user interaction patterns. Those patterns are retrieved from user actions to perform some specific tasks. When matching current user behaviors with an interaction pattern, the system may help the user to execute the upcoming associated tasks. Our method follows their approach. However, instead of depending on VRML sensors to track user traces, we capture user data with a technique compatible with modern Web3D applications running on Mozilla Firefox or Google Chrome, etc.

Mortara and Spagnuolo (2009), Laga (2010) applied semantic-based approach to analyze 3D shapes and extract their meaningful parts. Computed saliency features are then automatically displayed as thumbnails to the user. The user can select a thumbnail to access a generated best view. The accuracy of this method, however, depends on the nature of 3D shapes and the computation process is heavy. Our work takes a different approach: we analyze previous user navigation in order to characterize ROIs in a 3D object. Interactive 3D poses, corresponding to the detected ROIs, allow the next generations of users to identify the 3D features more quickly with fewer interactions.

OUR PROPOSAL

Approach Overview

We propose a new paradigm to improve Web3D user experience. The first goal of this paper is to show that user navigation traces can be used to detect interesting regions of the 3D model. For that, we artificially create a ROI on a 3D model by adding a stamp (see figure 2). We then show that by analyzing the navigation of a limited set of users, we can automatically give recommendations to the subsequent users to ease their navigation. We propose a setting for the recommendation, and quantify by a user study the increase in performance of users given recommendations.



Figure 2: 3D Models with Added Stamps.

Our method includes three main parts (see figure 3). First, we collect 3D interactions from a set of initial users (first column). Collected data, including visible 3D points, camera position and normal vectors on each user created frame, are sent back to server and stored into a database. This is our crowdsourcing part. The second step analyzes the logged traces to automatically detect ROIs, that are the parts on the surface of the 3D object and appear the most through crowd navigation (second column). The goal is to identify informative regions containing high density of logged 3D points. Second column of figure 3 shows two examples of detected ROIs marked by two red circles: each region contains a stamp (one on the chest and one on the knee of the statue). In the last step, we compute corresponding poses, *Recommended views* such that the ROI is at the center of the viewport (third column). Recommended

Views are then proposed to the next generations of users via a set of clickable buttons so that they may use or not.

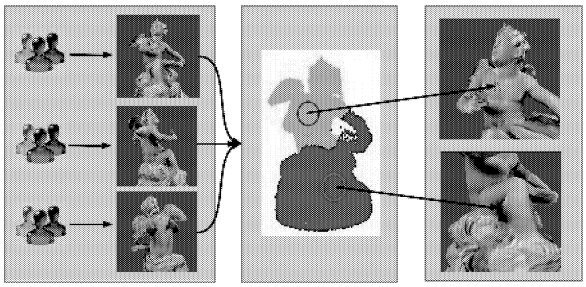


Figure 3: Approach Overview: navigation data created by different user interactions (first column), an example of two detected ROIs (second column), their corresponding Recommended Views (last column).

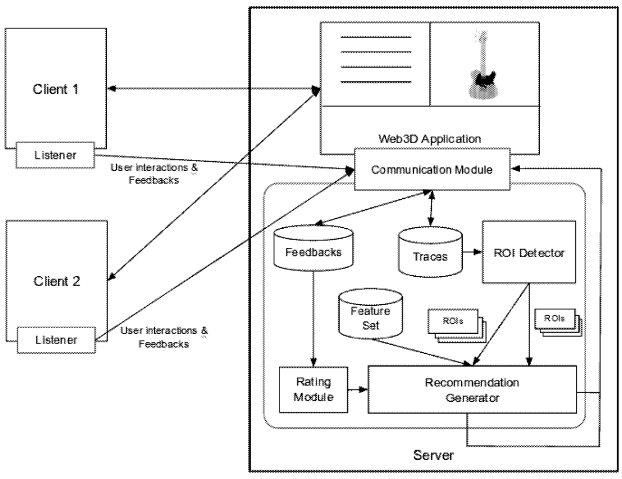


Figure 4: System Architecture.

System Architecture

We introduce a system architecture to implement our method (see figure 4). Basically, our system acts as an extension for the existing Web3D application. At the client side, the *Listener* component captures user interactions and sends data back to the server by remote requests (XmlHttpRequest). At the server side, the *Communication Module* acts as a communicator among the Web3D application, client requests and our system core (ROI Detector, Generator, Rating Module). In the system core, the *ROI Detector* analyzes the logged data to determine informative regions which are then used by the *Generator* to compute recommendations. The other component in the system core is the *Rating Module* which collects crowd feedbacks and opinions to continuously enhance recommendations. The evaluation of this component was introduced by Nghiem et al. (2012). In the next subsections, we present the implementation of our system for Web3D application using x3dom rendering engine (X3DOM 2013).

Collecting User Traces

We collect visible 3D points on each frame using the 3D picking buffer technique proposed by Behr et al. (2010). In more details, the scene is rendered into a texture attached to a framebuffer object: the normalized world coordinates of 3D points corresponding to visible 2D points on the canvas are encoded into the RGB channels. Each time a user creates a frame, those 3D coordinates are retrieved and sent back to the server as collected user look-at points.
In each frame, we extract the camera position from the current view matrix and compute the distances between the camera and the visible points. A shader program also captures the normal vector at each visible 3D point.

Regions of Interest Detection

In order to characterize the ROIs from the collected 3D points, we use a Mean-shift clustering technique (Comaniciu and Meer 2002). We chose Mean-shift for its robustness (we do expect outlier in navigation/users).
Two points need to be addressed when using Mean-shift: (1) the metric of the feature space, and (2) the shape of the kernel. For (1), fortunately, our feature space is Euclidean since logged points are on the surface of real 3D objects. We choose a flat kernel for (2) to ensure the convergence of Mean-shift. The output of the algorithm is a set of clusters, presenting detected ROIs. Each cluster contains a mode and the corresponding data points. The area around the mode is the most informative region of the cluster. The mode's position is intrinsically very close to the object surface thanks to the metric and the flat kernel properties. Each cluster gives a ROI defined by its center, the point of the collected data nearest to the mode, and its size, the number of points in the cluster.

Recommended View Generation

We compute recommendations such that the ROI is at the center of the viewport. The method is to set the camera position and orientation so that it looks towards the ROI center. To do so, we first extract the logged normal vector at the ROI center and set it as the camera look-at vector. Next, we get the median of the collected distances between the ROI center and the camera. Using this median, the ROI center and the normal vector, we calculate the camera position. Having camera position and look-at point, a conversion is computed in order to get camera orientation (Chenney 1995). Each

time there is a request for recommendation from users, a new camera with computed orientation and position is set to generate the recommended 3D view.
We introduce recommendations to subsequent users with a set of clickable buttons (Recommendation, Original, Next, Previous), positioned above the 3D rendering area. The user can ask for a specific recommendation by clicking one of our proposed buttons.

EXPERIMENTS

In this section we describe the experimental setup of the user study and an analysis of the results in order to evaluate our method.

Set-up of the Experiments

In this project, the user study has two main goals. We need to collect interactions of the first sample of users while they are completing the motivation task, in order to generate recommended 3D views: this is the crowdsourcing part. Then in the second step, we propose recommendations to another sample of users that will allow us to properly evaluate the effectiveness and the quality of these recommendations. This user study was performed on a total number of 28 users, 18 of them being part of the crowdsourcing step and 10 others evaluating the recommendations; 17 users were male, 11 were female and their age ranges from 23 to 35.
The interface allows users to zoom, pan and rotate around 3D objects. We recorded every interaction into our database. We used two 3D models from 3DCOFORM (2013) (see figure 2) for the user study, called *ManStatue* and *VaseWhite*. *ManStatue* is a rather complex model whereas *VaseWhite* is a simple model, presenting a lot of symmetry.
The purpose of this user study is simple. We provided the crowd an explicit task so as to motivate them into their navigation. We gave them 6 models of ancient statues, called *ManStatue*s (MS1, MS2 and MS3) and *VaseWhite*s (VW1, VW2 and VW3) respectively. Each statue has a stamp containing information about its manufacture date at different places; on the knee in *MS1*, on the chest in *MS2*, on the left wing in *MS3*, on the white part in *VW1*, on the yellow part in *VW2* and on the top in *VW3*. A statue is considered as more valuable if its manufacture date is older. The motivation task provided to the crowd is to locate the stamps in order to get the oldest manufacture date presenting the most valuable statue.
The first step of our user study was divided into three successive parts. First we explained our interface with available interactions to users and let them try it by themselves on an additional 3D model. Then we introduced the motivation task as well as showed them what the stamp looks like on a 3D model. At this point we want users to fully understand what is expected from them before executing the task. Finally we provided the users with the six test models, in a random order to avoid some undesirable side effects. We recorded the time and interaction taken by users to complete every task.
In the second step of the user study, we modified the interface to introduce a new interaction. Users could press a button to explicitly ask for a recommendation. These recommendations were computed using our method on the data gathered during the first step of the user study. Apart from that, we followed the exact same protocol for the second step of the user study as for the first step.

Results

Figures 5 presents the recommended 3D views computed using interactions collected during the first step of our user study. The recommendations succeed in recovering the locations of the stamps. It shows that characterizing ROIs from user navigation traces is possible. As can be seen from the figure, the users can access different recommended views by clicking the supported buttons (Next/Previous).

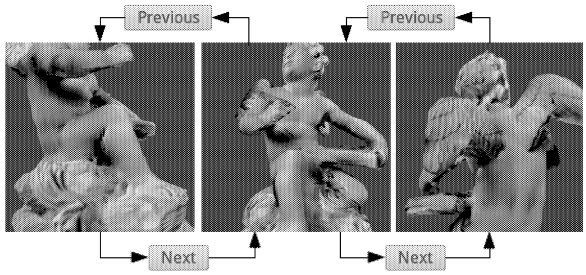


Figure 5: Recommended Views accessed via Clickable Buttons.

Table 1 demonstrates the average time taken by users to locate the stamps on the 3D models at each step of the user study. It is clear when looking at this table that the users from the step 2, who were given recommendations based on traces of users from the step 1, are quicker to perform the task than users from the step 1. This result presents that our recommendations are able to guide users to the regions of interest of the 3D models. Moreover, table 2 shows that users generally used less interactions to reach the target during the step 2 of the user study than during the step 1. The recommendations may also help users in reducing negative interactions in case of heavy 3D data.

	MS1	*MS2*	*MS3*	*VW1*	*VW2*	*VW3*
Step 1	76	48	67	53	50	54
Step 2	11	9	8	7	8	6

Table 1: Average time (in seconds) taken by users to complete tasks, for each step of the user study.

	MS1	*MS2*	*MS3*	*VW1*	*VW2*	*VW3*
Step 1	192	108	153	128	126	133
Step 2	29	22	20	17	21	15

Table 2: Average number of zoom, pan and rotate events created by users to complete tasks, for each step of the user study.

The results show that we were able to generate useful recommendations by gathering data from 18 users. It is necessary to know if our recommendations would converge to the same regions of interest even if we were to use less users.

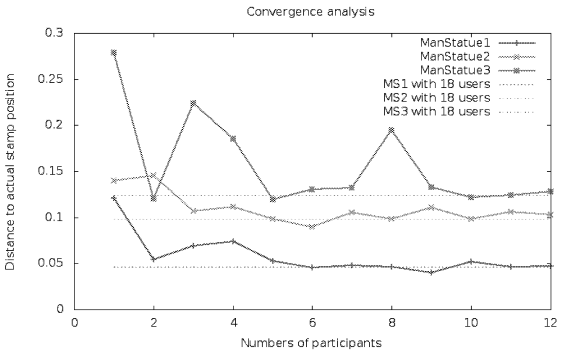


Figure 6: Correctness of the center position, depending on the number of users taken to compute the recommendations.

So, we select n random users out of 18 users, then compute the recommendations using only the interactions of those n users. The output of our method is a 3D point (corresponding to a mode out of the Mean-Shift algorithm). We can then compute the distance between this 3D point and the actual 3D position of the stamp (see figure 6). By taking a high number of permutations and averaging the distances we get a point on the diagram. The results show that the method converges with approximately 10 users in order to get the same precision for the recommendations as we have with 18 users (represented by the horizontal lines).

CONCLUSION AND FUTURE WORK

This paper proposes a new crowdsourcing approach to improve Web3D user experience. Our method is to detect ROIs through crowd navigation and then create recommendations based on those ROIs for the next generations of users. A user study shows that the recommendations can recover the important region reliably, even with a small members of users. We also show that the recommendations are useful for subsequent users.
In future work, we plan to handle more type of interaction by analyzing interactions on 3D content through a tactile device. Also, we want to use the analysis of user interaction to enrich 3D content. Specifically, we may analyze the interaction between textual description and 3D data in order to create semantic information attached to the 3D content.

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PRODUCTION DESIGN OPTIMIZATION

GLOBAL OPTIMIZATION TECHNIQUES IN THE DESIGN OF THE ELECTRIC POWER LINES

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KEYWORDS

Concurrent engineering design, assessment of costs, CAD simulation, linking CAD with database systems

ABSTRACT

The design process of an electric line is time consuming because it needs an integrated tool for assessing the overall investment cost. The following paper presents a new IT concept for designing electric lines using CAD environments facilities and knowledge database management. One of the newest fields of application of this design tool is the integration of renewable energy resources in the national electric power grid. Using a DBMS, the authors built a simulation tool integrated in a CAD environment, based on the cost assessment. The new concept was successfully implemented in some companies.

INTRODUCTION

Power transportation lines are a widely used way to transfer electric power from production plants to end- consumers. These lines consist mainly of transformation stations, sustain towers and wires.
A transportation line, as an exact concept, is very complicated to design, due to the many parts that form the towers, the linking accessories, the wires and the foundations [Eremia 2006]. Complete CAD concepts of these lines are far too expensive to be done before the constructor knows if he will be chosen as contractor, following the usual auction.
The information from the auction specifications must easily be converted into a brief concept that accurately simulates the line leads a fast assessment of construction costs. This cost assessment could be a decisive aspect in choosing between several offers that have the exact same quality requirements and completion calendar.
Concurrent engineering can offer the most accurate and balanced cost assessment, by using a CAD based simulation tool, coupled with a database of cost oriented investigations.
Simulating through a CAD concept implies a special CAD application that helps the designer obtain a quick and concise overview of the entire electrical line.
The CAD tool must accurately design the tower placement and must allow the designer to place the towers and edit their properties.
A fully integrated scaling tool is needed to correctly scale the design, which usually has different scale factors for length and height of the line.
One also needs a skilled wire representation tool that computes scales and draws the wire concept. The application also provides the automatic redrawing of the whole wire scheme, whenever the designer requires it. Also, there is a need for a design data export tool, linked with the cost assessment tool.
All these preliminary features can be implemented using a smart open CAD System (such as AutoCAD) and a powerful application programming system like AutoLISP.interact with are complex and expensive systems.

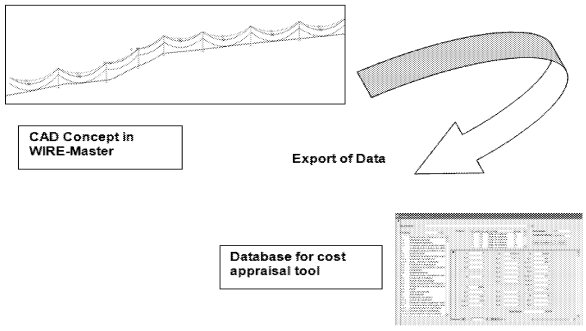


Figure 1 Overall Data Management concept for cost assessment

The CAD concept was implemented at high-end class into PLS-CADD™ from Power Lines Systems Inc [Jacobs and Lake 2013].
Other competitors are TLCADD™ and LD-Pro™ programs available from LineSoft® Corporation

WHY AUTOCAD?

CAD Systems are often closed or unfriendly to developers. Most of the time, these are too complicated and developers have to use high-level programming tools, as well as a complicated system of libraries that opens up the structure of the graphic database.
AutoCAD is a powerful drafting tool and it allows for 2D or 3D designs to be released in a very accurate form, using

a well-known graphic database. Since the purpose of this simulation is a 2D issue, AutoCAD appears to be the best choice, due to its power in 2D drafting.
Programming in AutoLISP has been very popular ever since the early beginning of using AutoCAD. Even if at first the language appears to be difficult, at a second approach it reveals itself to be a simple, elegant and intelligent tool. It offers full access to the graphic database, a fully equipped programming language and an integrated programming space for developers (VisualLISP), a pack of ready to use facilities, able to solve intelligent tasks, such as the present one.

SCHEMATIC REPRESENTATION OF TOWERS AND WIRES

A tower must be drawn in a simplified form and it must store a certain amount of information that reveals his properties. The simplest representation is shown in figure 2.

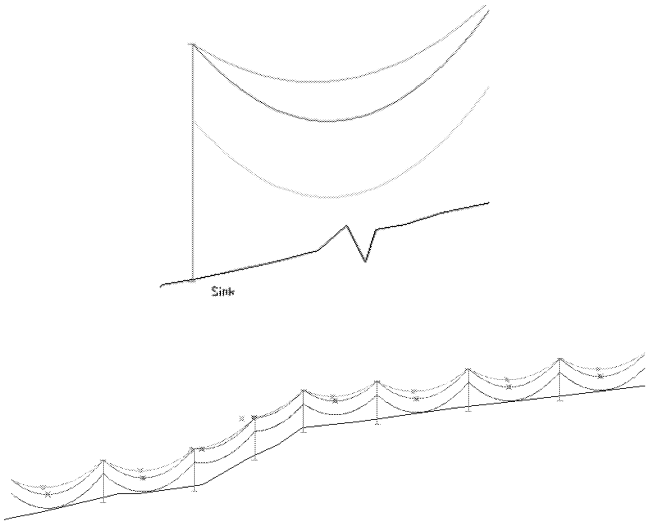


Figure 2 Schematic representation of one tower and of a part of the line

The tower is drawn as a vertical line, with two horizontal marks for the top and the bottom. The placement of the tower matches the topographic profile, having a certain sinkage.
Emerging from the tower tops, two wires are shown - one green for the cold wire and one red for the hot wire. A third curve is the guard curve that offsets the red curve on a certain distance. The Guard curve must not intersect the topographic profile and the guard distance is different in open spaces or for areas with inhabitants.
All objects respect different scale factors in length or height of the construction. The most often used scales are 1000:100 and 2000:200. The drawing uses these ratios and the whole construction can be resized on a new combination of scale factors.

The properties of one tower are stored as associated data and form a set that can be easily edited, printed or exported to other applications.
In order to make a new tower, to edit its properties, to move or to delete towers, a set of tower management tools was developed.
The tower is a complex entity that must be erased with all his parts, so the selection of a tower is completed by a special selection tool that discovers and selects all the tower parts, even if the selection is made on a specific part. This mechanism is also used when moving towers.
Even if the tower appears to act as an AutoCAD block, the complex entity is not a block and each part can be changed independently (for changing colors or line types, for example)

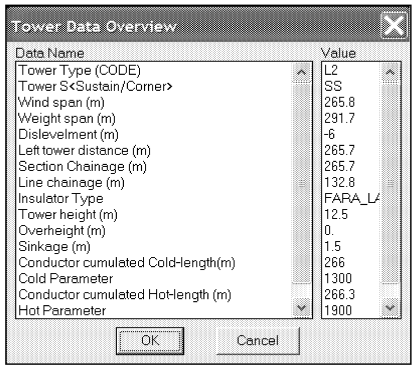


Fig. 3 Set of associated data of a tower

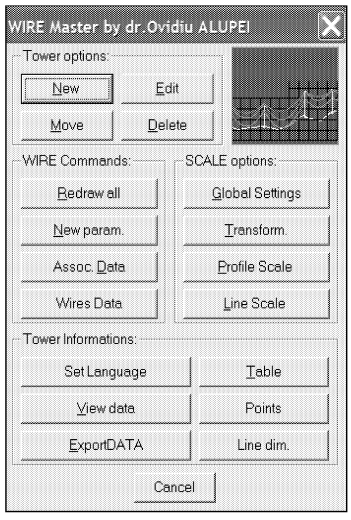


Figure 4 Main dialogue box of WIRE Master

REDRAWING WIRES

The wire always connects the precedent tower with the current one. The tops of two towers are the start and end points of the curve, which is computed exactly to fit on these extremities. The parameter of the curve is related to the pre-stress conditions imposed to a wire, which is specified by the advised user.

The design of a line requires many adaptations, such as inserting new towers, moving, deleting, changing parameters of wires etc. All these activities lead to changes in the wire configuration and must be followed by a complete deletion and a redraw of all wires.
The program performs an impressive global deletion and redrawing, this tool being one of the most powerful and efficient on the market.

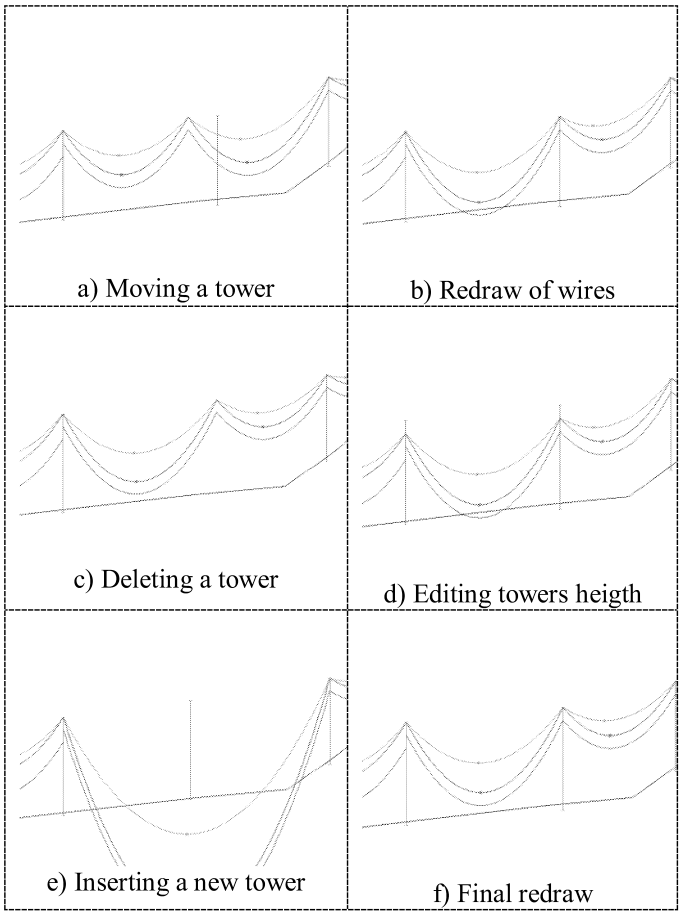


Figure 5 Snapshots on tower management and wires automatic redraw

DATA MANAGEMENT

The program is designed to edit, print and export information about the whole line. Some of the information must be drawn on top of the design, such as a table that follows each tower and contains the extended data related whit the tower's structure. The information is available in three languages: English, German and Romanian. All the command dialogues and dialogue boxes are designed to respect the selected language.
The export of data to an external file uses a .CSV specification, which means the information columns are separated by commas. This format is very common and is recognized by a large number of other office applications such as MsExcell or MsACCESS. The export simplifies the transfer of data that comes from the drawn concept of the transportation line to a program that performs the assessment of its costs.

BUILDING THE COST ASSESSMENT TOOL

The central idea of cost assessment is to build a program that stores the specific amount of used towers ant the total length of the used wire. The towers used to build a transportation line are often classified into specific dimensions and are usually part of classes. For each class, the towers have a specific list of costs that are stored into the database and can be used to compute the overall construction cost for each tower class. Wires are also classified and the linear cost of each wire class is to be stored into the database.
The main challenge is to build a program that also stores command numbers, along with their description and beneficiary, variants of the designed construction and a suite of queries that select, compute and prepare information that is to be presented into a cost assessment report. For this purpose, a conceptual database program was conceived and will shortly be presented. The application's dialogues and results are written in Romanian language, to be used as demonstration.

DATABASE STRUCTURE

The database is structured in tables that are linked through relations, forming the relational and functional structure which is shown in the following figure:

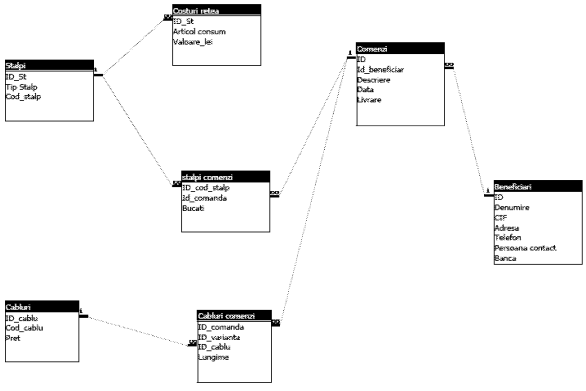


Figure 6 The functional diagram of the database

A complete set of forms were developed in order to accurately describe the components of the transportation line formed from towers and wires.
For the purpose, one can automatically import the data gathered in a buffer table, or fill in the complete tower and

wire description by hand. There is also an editing form for making the very last adjustments to the line composition, if it is required.

The main form is represented as a computing center that allows the user to select the current command number and the work variant number, a list containing all computed categories, being used as index of terms. A columnar sub-form gathers all the cost assessment categories and shows a dynamic computation of all costs and a list of current towers assigned to the command.

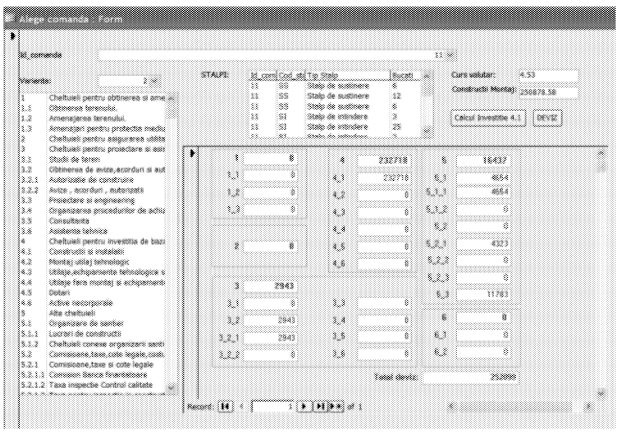


Figure 7 The main form for computing the cost categories

The form has two buttons - one for computing and updating the appraisal category of "4.1 Constructions and installations" and another to launch the written report. A textbox for the actual exchange rate is provided, in order to compute the report using both currencies.

The form is easy to use: after selecting the command number and variant from the provided combo boxes, the user has to insert the currency rate, in order to calculate the investment cost and to print the report.

The cost categories are interconnected with mostly automatically computed formulas.

Other cost categories, which are particularly involved into the current command, must be filled in by the user (cost for land acquisition, costs for training of workers etc.).

The automatic construction cost assessment is provided by a sophisticated system of queries that prepares, computes, updates and appends the information into the designed tables.

When appending a new tower class, one needs to create the new class description beforehand and to fill in the concerning information about materials, manpower and other cost categories in the class cost table.

Even if this is a proof of concept database, it demonstrates all the required capacities and strengths of a strong and efficient tool. It can be easily adapted into a business oriented application, tailored to the client's needs.

The report has specific content that summarizes the information on the command in its header and reveals the computed results for each cost category in both currencies, with and without VAT.

The report is also customizable to client requirements and can be additionally enriched with a whole suite of reports that can assess costs based on material or manpower consumption.

Further collaborations with specialized construction companies can lead to better business oriented sets of reports, in addition to the basic reports used in assessing such a technical-economical effort.

Chapter	Value	LEI+VAT	EURO+VAT
1	**Costs for obtaining and improving the land**	**4712.00**	**1,070.91 €**
1.1	Obtaining the land.	1860.00	422.73 €
1.2	Improving the land.	2852.00	648.18 €
1.3	Environment protection.	0.00	0.00 €
2	**Expenses for necessary utility services**	**248.00**	**56.36 €**
3	**Expenses for design and technical assistance**	**17210.13**	**3,911.39 €**
3.1	Field studies	1488.00	338.18 €
3.2	Obtaining permits, approvals and authorizations	7680.73	1,745.62 €
3.2.1	Building permit	7680.73	1,745.62 €
3.2.2	Permits, approvals and authorizations	0.00	0.00 €
3.3	Design and engineering	6820.00	1,550.00 €
3.4	Organizing public procurement procedures	372.00	84.55 €
3.5	Consultancy	849.40	193.05 €
3.6	Technical assistance	0.00	0.00 €
4	**Expenditure for basic investment**	**633184.81**	**143,905.6 €**
4.1	Construction and equipment	604168.84	137,311.10 €
4.2	Installation technological equipment	0.00	0.00 €
4.3	Equipment technical and functional	24800.00	5,636.36 €
4.4	Machinery and transport equipment	0.00	0.00 €
4.5	Features	4216.00	958.18 €
4.6	Intangible assets	0.00	0.00 €
5	**Other expenses**	**44820.12**	**10,186.39 €**
5.1	Construction site arrangement	12145.38	2,760.31 €
5.1.1	Construction work	12145.38	2,760.31 €
5.1.2	Associated costs of organizing the site	0.00	0.00 €
5.2	Fees, taxes, legal, financing costs	0.00	0.00 €
5.2.1	Commissions, legal fees and allowances	11477.03	2,608.42 €
5.2.1.1	Bank financing fees	0.00	0.00 €
5.2.1.2	Quality Control inspection fee	0.00	0.00 €
5.2.1.3	Construction inspection fee	0.00	0.00 €
5.2.1.4	For contribution. Social House Builders	0.00	0.00 €
5.2.1.5	Insurance premiums	0.00	0.00 €
5.2.1.6	Other expenses	0.00	0.00 €
5.2.1.7	Taxes ANRE	0.00	0.00 €
5.2.2	Cost of credit	0.00	0.00 €
5.3	Miscellaneous and unforeseen	32674.74	7,426.08 €
6	**Expenses for technological and customer tests**	**0.00**	**0.00 €**
6.1	Training of operating personnel	0.00	0.00 €
6.2	Technological tests	0.00	0.00 €
7	**Total Estimate**	**700175.06**	**159,130.7 €**

Figure 8 The automatically generated report

CONCLUSIONS

Assessing the construction costs of an electrical transportation line is often a complicated job that involves many design tasks, along with using specialized computing

programs. This implies a long and tedious process that takes a toll when preparing for an auction.

The WIRE-Master CAD tool, showcased in this paper, provides an easy to use, versatile and precise conceptual simulation of the entire transportation line.

The paper also showcases a cost assessment proof of concept that links the information exported from WireMaster, offers complete computation power and provides a comprehensive cost assessment database.

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BIOGRAPHIES

OVIDIU-DORIN ALUPEI-COJOCARIU graduated in Manufacturing Technology Faculty from University POLITEHNICA of Bucharest in 1986, and a PhD in Mechanical Engineering in 1999. He became an AutoDesk Authorized Trainer in 1996 and teaches courses about CAD/CAM, Databases for Engineering and Management, Management of RDI Projects and Product Data Management as Associated Professor in the University POLITEHNICA of Bucharest. He has developed many AutoLISP first class applications during 1996-2012, mainly for the industry.

SZILARD FEHER graduated in Mechanical Engineering from University POLITEHNICA of Bucharest in 2009, and a MD in Advanced Hydraulic and Pneumatic Systems in 2011. The same year he began a PhD research work on mobile electro hydraulic servo systems at the Fluid Power Laboratory from the Power Engineering Department of the University POLITEHNICA of Bucharest. He serves currently as technical advisor for the company HIDRAULICA SRL from Brasov, a PARKER HAN industrial applications developer.

NICOLAE VASILIU graduated in Hydropower Engineering from University POLITEHNICA of Bucharest in 1969. He became a PhD in Fluid Mechanics after a research stage in Ghent State University and the Von Karman Institute in Brussels. He became state professor in 1994, leading the Fluid Control Laboratory from the Power Engineering Faculty of the above university. He worked always for the industry, as project manager or scientific advisor. He was also leading five years the Romanian Innovation Financing Agency.

Multi-camera complexity assessment system for assembly line work stations

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KEYWORDS

Multi-camera, manufacturing complexity, production engineering, visual hull, image analysis

ABSTRACT

In the last couple of years, the market demands an increasing number of product variants. This leads to an inevitable rise of the complexity in manufacturing systems. A model to quantify the complexity in a workstation has been developed, but part of the analysis is done manually. Thereto, this paper presents the results of an industrial proof-of-concept in which the possibility of automating the complexity analysis using multi-camera video images, was tested.

INTRODUCTION

Manufacturing plants are constantly pushed towards higher quality, lower cost and more product variety. Increased product variety is necessary to meet the changing customer and sustainability demands, but it also entails an increase of the complexity of (re)designing processes and workstations.
Zeltzer et al. (2012) proposed a clear and objective definition of the complexity of a workstation. Furthermore, the main drivers of complexity were determined and used to analyze work stations and categorize them as high complex or low complex systems.
Some of the information needed for this complexity assessment can be captured directly from the Enterprise Resource Planning (ERP) or Manufacturing Execution System (MES), but part of the data capturing is still done manually. This paper presents a field-test within a company in the automotive sector, where multi-camera video footage was used to automate the data capturing at the workstation. The workstation that was investigated is part of the rear axle assembly line, which produces rear axles for 3 different models.
The paper starts with an introduction to the video analysis technology and the explanation of the algorithms used to process the images. Further, we clarify how the captured data was translated in information that is useful for the complexity model and we present some results. We then finalize the paper with the conclusions and future research.

LITERATURE REVIEW

Not a lot of research had been done to date on the level of complexity of a manufacturing system. The first effort to quantify the effect of complexity on the performance of automotive plants was made by MacDuffie et al. Following their research, the part complexity is the only element that has a consistent negative effect on the performance of such a production system. ElMaraghy et al. (2003) state that the complexity is related directly to the quantity, diversity and content of the information that is passed to the human in the system. They also captured the complexity of a production system in an index, which is primarily based on the information needs (ElMaraghy et al, 2004). Zeltzer et al. (2012) proposed a clear and objective definition of the complexity of a workstation. They were also the first to develop a model that quantifies the relationship between complexity as perceived by the operators and its drivers.
The use of video recordings in a manufacturing environment is not completely new. For years, industrial engineers are using films to perform time studies using Predetermined Motion and Time Systems (PMTS). Video clips are very efficient to document the work method (Karger and Hancock 1982, Konz 2001), but the inability to derive exact distances from the images lead to inaccuracies in the results. Elnekave and Gilad (2006) developed a rapid video-based analysis system that is able to translate distances accurately from the picture frame into real distance values of the workstation by using digital mapping. Dencker et al. (1999) presented a video-based system which served as a training tool for operators on the one hand and as an information system on operations on the other hand. Furthermore questions of ergonomics or health and safety issues at the workstation were taken into account. At Nexteer, a supplier of automotive parts, 2D video analysis software is used for continuous improvement of their processes. By overlaying the images of 3 different operators at the same workstation, differences are demonstrated and used to improve and standardize the work method.
Although video images are commonly used in industry, there is to the best of our knowledge no system to date that uses multi-

camera footage to determine the complexity of workstations and detect waste in assembly processes.

VISUAL HULL EXTRACTION

Position extraction

To calculate the position of the subject on the ground plane, a multi-camera setup is utilized. This setup enables us to approximate the 3D shape of an object in the overlapping field of view (FOV) of the cameras, otherwise called the visual hull (Laurentini, 1994). A visual hull is generated by first constructing, for each camera, a generalized infinity cone in the 3D space with the camera position being the apex, and the silhouette in the camera view as the base. The visual hull is then the intersection of these cones. We approximate the position of the subject by projecting the visual hull's center of mass onto the ground plane.

Silhouette extraction

The silhouettes, commonly represented as binary masks, are typically produced by foreground/background segmentation algorithms based on, amongst others, static background models (Kim et al., 2007) or motion detection (Zivkovic et al., 2006). Commonly, such algorithms are only able to provide usable foreground masks when operating in a highly controlled environment. The ambient space in a factory hall however, is largely composed of moving objects. Moreover, many factory halls have large north face windows in the roof, bringing additional global lighting changes. Therefore, typical foreground/background segmentation methods proved to be unsuitable in this application. To overcome these issues, we outfitted the subject with a yellow fluorescent vest that is clearly distinguishable from the background. Hence, the segmentation process is primarily based on color information. We propose to convert the image to YUV color space for enhanced robustness against lighting changes. The process of extracting the foreground from the input video sequences is explained in Figure 1.

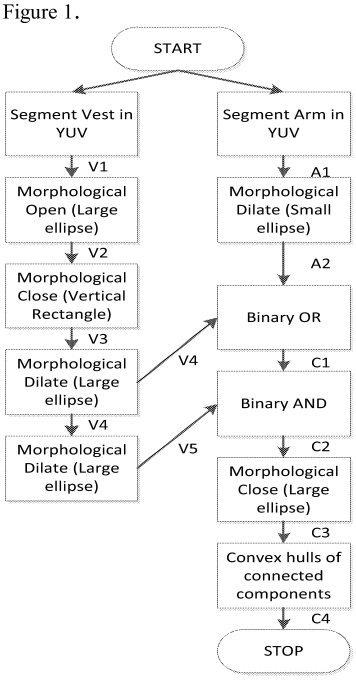


Figure 1: Segmentation algorithm outline

The first stage is to obtain a rough segmentation of the fluorescent vest from the input Figure 2 by using an empirically defined double threshold in the YUV color space. This segmentation (V1) is then post processed using a morphological opening to eliminate noise (V2). Since the fluorescent vest is supplemented with gray horizontal stripes, an additional morphological close operation with a large vertical rectangular structuring element is performed. At this stage, a rough segmentation of this vest is attained (V3). Incidentally, this mask is frequently partially occluded by the bare arms of the subject. To incorporate this, an additional double thresholding step is introduced to obtain a rough segmentation (A1) of the arms of the subject from the input image. Then, V3, and A1 are dilated with an ellipsoidal structuring element, in order to make these masks overlap each other when supplemented on each other (C1). Since bright yellow is far less likely to occur than skin color, a region of interest is generated by dilating V4, the result of which is subject to a binary and operation with C1. Any residual holes in C2 are filled with a morphological closing operation. Finally, we eliminate any concavities in the resulting foreground regions by calculating the convex hull of each of the connected components. This is beneficial in computing the visual hull, as these concavities typically depict the shoulders of the object. Figure 3 shows the resulting foreground mask for a single camera.

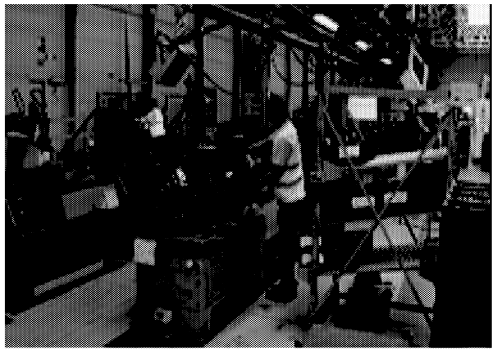


Figure 2: input camera image



Figure 3: final foreground mask of single camera

3D shape reconstruction

In this work, the visual hull is constructed by means of voxel carving. First, the 3D space is discretized into voxels. Any voxel is part of the visual hull if its projection onto each of the cameras planes lies inside the respective silhouette. In essence, each camera carves away regions of the 3D shape that do not project onto its silhouette, resulting in a recognizable 3D

shape. Figure 4 shows the generation of the visual hull of a person for 1, 2, 3 and 4 cameras respectively.
Note that to guarantee a precise visual hull, the quality of both camera calibration parameters (both intrinsic and extrinsic) and the extracted silhouettes are paramount. Furthermore, the visual hull is not necessarily convex, since cavities in the silhouettes are carved out of the 3D shape as well. As the process of depth carving solely considers light rays being blocked by the actual object, concave surfaces on the real object are represented as planar surfaces on the visual hull. This problem can be resolved, however partially, by increasing the number of distinct viewing angles as this increases the level of detail of the resulting 3D object, or by changing the position of the cameras so as to view the concavity from a more sideways position. Indeed, the visual hull is highly dependent on the camera positions.

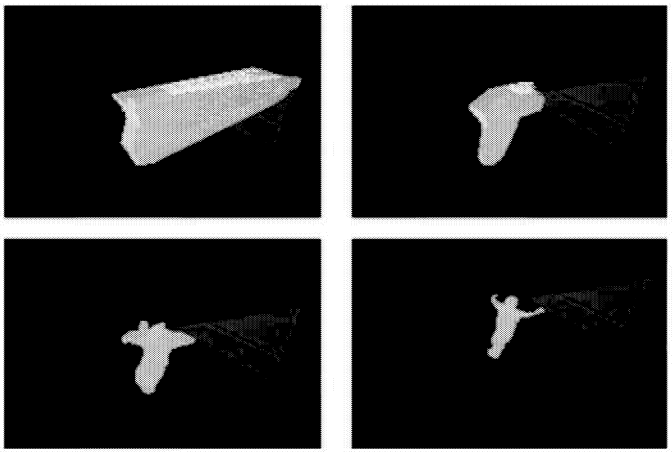


Figure 4: Principle of voxel carving with 4 viewpoints

DATA PROCESSING

The output of the image processing is a sequential list of 3-dimensional coordinates which describe the position of the operator for every frame (20ms) in the video recordings. Theoretically, three cameras should be sufficient to calculate these positions. In practice, adding a fourth camera helps to eliminate noise in these results. This is shown in Figure 5 and Figure 6 in which all positions visited by the operator during the recordings are depicted, based on the data obtained from respectively three and four cameras.

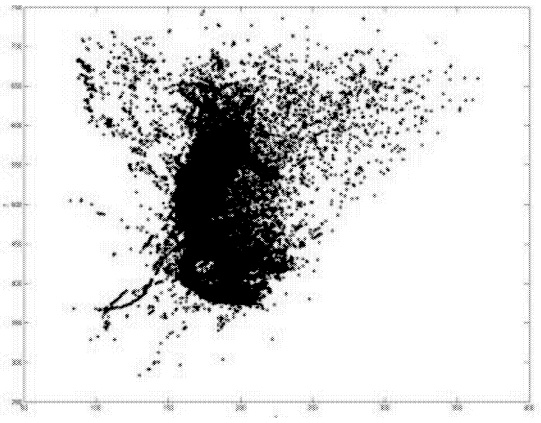


Figure 5: Locations visited by the operator (3 cameras)

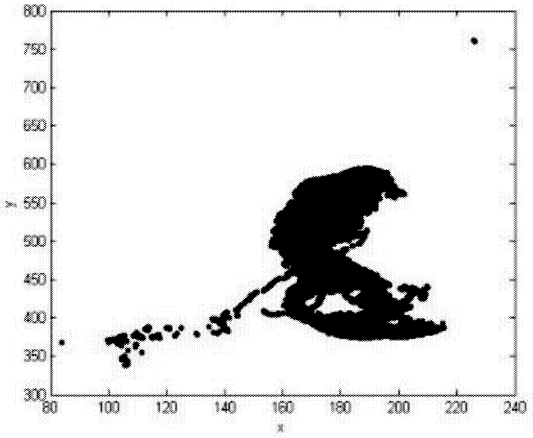


Figure 6: Locations visited by the operator (4 cameras)

Routing diagram

To see how the operator moves through the workstation, a routing diagram is constructed. To overcome the inaccuracies in the data, we take the moving average position over 1 second. In the routing diagram, these average locations are plotted for every 0.5 seconds of a total work cycle of 43.5 seconds. This results in a routing diagram as shown in Figure 7.

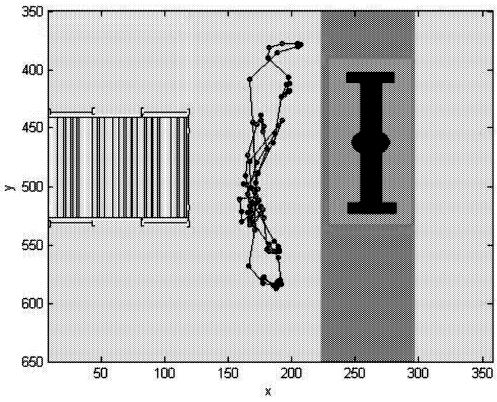


Figure 7: Routing diagram

Work load variation and fluctuation

Substantial variation in the cycle time can indicate the presence of high complexity in the work content. To investigate the possibility of deriving the cycle time and the fluctuation of this cycle time, a twofold method was used.
In the first phase, we select a (great) number of frames in the recordings and look for frames where the operator visits the same location he visits in the starting frame. The starting frames are randomly selected from the first minute of the video footage. To decrease the calculation time, we only calculate the distance of the operators starting position for a certain number of frames. Therefore, another random number is determined for every starting location and the method jumps through the data using this number as a search interval. For these selected frames, the method calculates the distance of the position in that frame to the starting position. If this distance is less than 3 cm, the frame number is saved in a list together with its corresponding starting frame. This list is used as the input for the second part of the method.

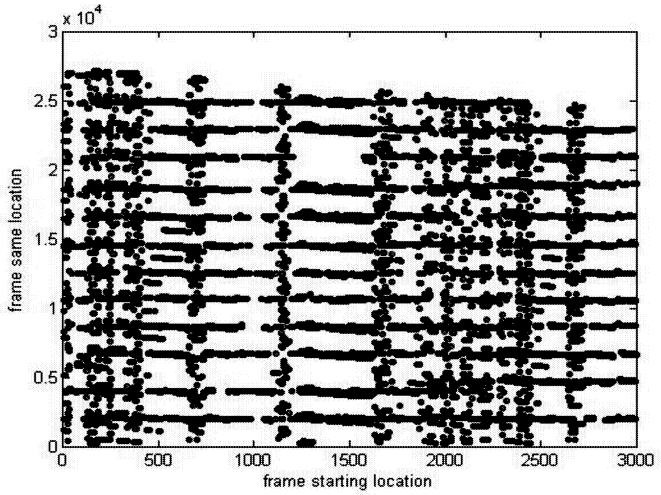


Figure 8: Samelocation Algorithm

Figure 8 shows the results of this method. On the x-axis, the selected starting frames are shown. The frames in which the operator visits the same location again, are shown on the y-axis. From a quick look at this graph, we learn that there is a clear pattern arising in these results.
The cycle time and its variation are calculated in the second phase of the method, by determining the distance between the lines in the graph above. For this, a 1-dimensional k-means clustering algorithm was implemented. This algorithm starts by determining the number of clusters in the dataset manually. We can derive from the graph that there are 12 clusters in this set. The starting solution can be constructed by selecting 12 randomly chosen points in the data range. Since we know that in the final solution the centroids of the clusters will be more or less evenly distributed over the data range, we divided the data range in 12 intervals and chose a random point in every interval. That way we were able to speed up the clustering algorithm.
The algorithm then calculates the distance of all data points to the centroids and assigns every point in the data set to the cluster with the closest centroid. Afterwards the new centroids of the clusters are calculated. The algorithm will repeat these steps until convergence.

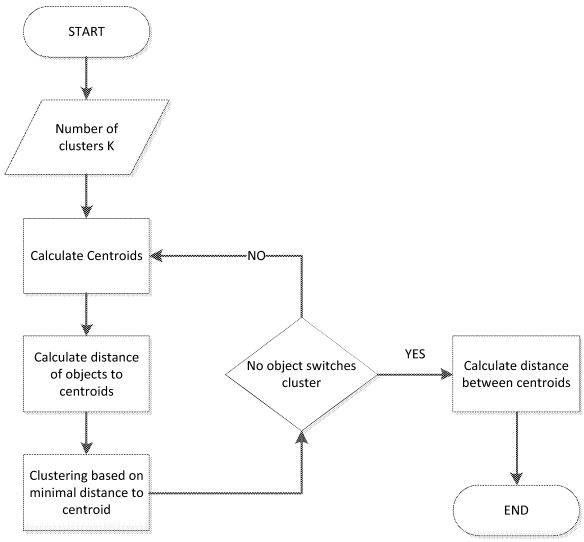


Figure 9: K-means clustering algorithm outline

The results of the clustering algorithm are shown in Table 1. The calculated cycle time of 43.5 seconds corresponds very well to the theoretical cycle time of 43.4 seconds the company take into account. Also the significant fluctuation in the work cycle agrees well with the video images.

Cycle time analysis		
Average C/T	43,5	sec
Standard Deviation	7,9	sec
Max/Min Ratios	57,42	%
	27,05	%

Table 1: Results cycle time analysis

Vehicle zones skipped

Unnecessary large walking distances may be an indication of a poorly designed process. To measure this, the area is divided in zones. Counting the number of times the operator passes such a zone without performing a value adding activity, can be useful to calculate the complexity and evaluate the design of the assembly process.
If we take a quick look at the video, we see that the operator passes the middle section of the axle quite often because a lot of the work is being done at both sides of the axle. The work station is divided in 4 zones, as shown in Figure 10.

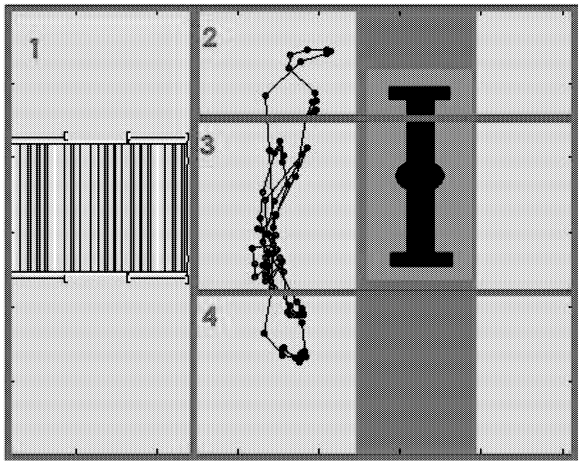


Figure 10: Vehicle zones skipped

To calculate this, an algorithm was implemented in matlab. The algorithm starts by determining in which zone the operator is located for every point in the data set. The pseudocode for this method is written down below. The input for this method is a consecutive list of the x- and y-coordinates of the locations visited by the operator and a list "zones" that is constructed as follows: $[x_{in,zone1}, x_{out,zone1}, y_{in,zone1}, y_{out,zone1}, x_{in,zone2}, \ldots]$.

function [inout] = ZoneDetect(path, zones)

INITIALIZE table "inout"

CALCULATE a,b and c coefficients for zone border equations

FOR length(path)
fill in the points in the equations of the zone borders to determine the position of these points to the borders

frame in	frame out	distance	time in	time out	theoretical walking time	real time	zone	1 if zone is skipped
16963	17167	2.78	339.74	343.82	0.05	4.08	4	0
17168	17245	19.29	343.84	345.38	0.36	1.54	3	1
17246	17674	30.11	345.40	353.96	0.56	8.56	2	0
17675	17730	8.29	353.98	355.08	0.15	1.10	3	1
17731	18239	6.65	355.10	365.26	0.12	10.16	4	0
18240	19026	13.18	365.28	381.00	0.24	15.72	3	0
19027	19215	0.10	381.02	384.78	0.00	3.76	4	0
19216	19305	19.29	384.80	386.58	0.36	1.78	3	1
19306	19671	33.84	386.60	393.90	0.63	7.30	2	0
19672	19728	10.99	393.92	395.04	0.20	1.12	3	1
19729	20229	5.93	395.06	405.06	0.11	10.00	4	0
20230	20644	10.46	405.08	413.36	0.19	8.28	3	0
20645	20705	5.24	413.38	414.58	0.10	1.20	4	0

Table 2: results vehicle zones skipped algorithm

```
FOR number of zones
        IF point is in zone
                        Add to inout
                        [X-coordinate, Y-coordinate, zone
                        number]
                BREAK;
                ENDIF
        ENDFOR
ENDFOR
```

Note that this method is not limited to 4 zones nor to rectangular zones.

To calculate this, the locations where the operator enters and leaves the zone are determined and the distance between these two points is calculated. Based on an average walking speed of 5km/h, the theoretical time the operator needs to cross the zone, is calculated. We can safely assume that the operator will perform some action in a zone, if he stays in that zone for a time that is significantly longer than that theoretical time.

We noticed that the real time needed to cross a zone is higher than the theoretical time based on an average walking speed of 5km/h. This can be explained by the fact that the operator usually isn't able to walk in a straight line and because he constantly needs to accelerate and decelerate. Therefore we say that the operator skips a zone if:

$$theoretical\ walking\ time.threshhold > real\ time\ in\ zone$$

An extract from these results (2 work cycles) is presented in Table 2. Again these results correspond well to the video, where we see that the operator regularly passes the middle section of the axle to go from the right hand side to the left and back.

CONCLUSIONS

In this paper, we presented an industrial proof-of-concept in which we investigated the possibility of automating the complexity analysis of an assembly workstation by using multi-camera video images. The current image processing technology can help us to automate the complexity analysis of a workstation of an assembly line.

For now, the focus was mainly on the position of the operator throughout his work cycle. More research should still be done on the recognition of hand motions and the viewing direction of the operator. Also linking the information we get from the video analysis with other sources of information such as MES-systems, ERP, RIFD tracking,… could be useful to translate more of the visual cues to complexity parameters.

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VIDEO APPLICATIONS

Researches on Depth Image Haptization System with Local Deformation

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KEYWORDS
Haptics, Image Haptization

ABSTRACT

In this paper we propose a depth image haptization system with local deformation. The purpose of this research is to improve the user experience and perception of the contents by adding 3D shape presentation and local deformation. The proposed system consists of a pc and a haptic device. A triangle polygon mesh is extracted and built from the depth image for the haptic rendering. Contact force between the contents and the user's finger is calculated with a proxy graph algorithm. In order to improve user experience, we perform a local deformation by applying displacement to the neighbor vertices of the contact vertex.
Evaluation experiment results suggest that adding local deformation to the depth image haptization improved the user experience and perception of the image contents in the proposed system. The results also suggested that the proposed system has better haptization quality, deformation effects and user experience than previous image haptization system.

Introduction

Haptic technology has been widely researched in recent years. A haptic device is a device which makes it possible for users to touch and manipulate virtual objects. PHANTOM OMNI®©Copyright 2012 Sensable. All Rights Reserved. (2012) by Sensable realized six degree-of-freedom positional sensing with a link mechanism. Novint Falcon®©2011 Novint Technologies Inc. All Rights Reserved. (2011)3D Touch controller is also a commercialized haptic device, which could provide a three degree-of-freedom force feedback sensation. SPIDARKim et al. (2002) is a tension based haptic device developed by Sato Laboratory which could provide a high-definition force feedback sensation Akahane et al. (2005)Akahane et al. (2006).
Haptic technology has been used in various interactive systems lately. Among these interactive systems, we are concerned about image haptization systems.
Haptization is a term which means making tangible, while image haptization system makes images haptically available for users to interact with a haptic device.
In our previous research, the 2D image haptization system with local deformationLiu et al. (2010) was proposed. The system enables users to obtain more than visual information from images. The system generates the haptic feedback from the image and allows the users to touch the image with a haptic device. The reacting force is calculated with the color information of the corresponding pixel and generated through the haptic device. Simultaneously, the image is distorted locally to simulate the deformation caused by the force.

In a later research an image haptization systemTakahama et al. (2011) using color's psychological effects and edge information was proposed. In this research an image haptization method using psychological effects of color was proposed and proved better user experience.

There are some limitations in the previous researches of image haptization system. For example only vertical forces could be generated from the color information of the image. User cannot touch the object from its side. Also the local deformation is always in a symmetric shape. These limitations could be resolved by adding the depth information.

Related researches about converting depth images into haptic data have been done in recent years. Rasool et al.Rasool and Sourin (2011) proposed a method combining the depth-based method with shading-based haptic texture rendering techniques to provide haptic sensation for depth image obtained from depth sensors. Rydén et al.Rydén et al. (2011) proposed an algorithm for haptic rendering from time varying point clouds captured using an Xbox Kinect RGB-D camera.

As for application systems, S. Walker et al.Walker and Salisbury (2003) developed an interactive 3D browser for large topographic maps using a visual display augmented by a haptic, or force feedback, display. Cha et al.Cha et al. (2006) proposed a 3D video player system that provides haptic interaction with objects in a video scene based on a depth image-based representation.

However, these researches do not involve deformation of the contents. We are proposing a haptization system for depth images with local deformation which could provide the users with haptic interaction with the 3D shape of the object and deformation effects. The purpose of this research is to improve the user experience and perception of the contents by adding 3D shape presentation and local deformation.

This research can be applied in various fields. For example, haptization of the product photos in an online shop may get more customers interested in the products and attract more potential buyers. Another application of this research may be used as a tool helping blinded people understanding contents of digital images.

System Overview

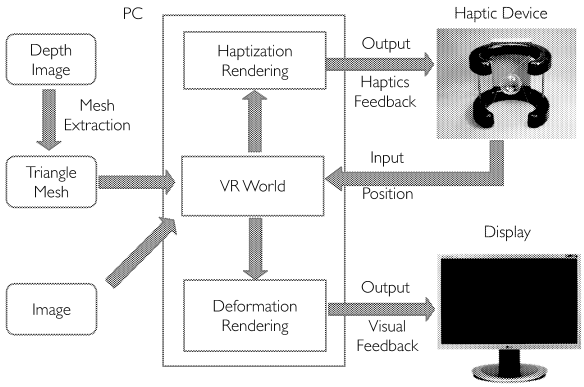


Figure 1: Configuration of the system

The proposed system consists of a pc and a haptic device. Figure.1 gives the configuration of the system. A triangle polygon mesh is extracted and built from the depth image. In the virtual world the polygon mesh is rendered and a pointer which indicates the finger tip of the user is also displayed. Through a haptic rendering and deformation rendering the user could interact with the contents of the depth image. In the haptization rendering, a proxy graph algorithm is used to calculate the contact force between the contents and the user's finger. In order to improve user experience, local deformation is applied by calculating the displacement of neighbor vertices of the contact vertex.

Depth Image Haptization

In this section, we will mainly describe how the haptization for depth images is performed.

Depth Images

Depth images have been used in interactive systems more frequently in recent years.
A depth image is a grayscale image of which every pixel stores the height. Obviously we can know that the height is ranged from 0 to 255. Usually a smaller value means a lower height, however reversed cases also exist. Figure.2 gives an example of depth image which has a resolution of 600x400. Depth images can be obtained from RGB-D cameras and depth sensors.

Mesh Extraction

In order to make the depth image tangible, we need to build a triangle polygon mesh from the depth image.
First of all we need to transform the 2D coordinates to 3D coordinates. For each pixel in the image, we use the image



Figure 2: Depth image

coordinates as the x, z coordinates and use the height as the y coordinate in the 3D coordinate system.

After the coordinate transform we can build a triangle polygon mesh from the depth image. For each four vertices, we have two triangles by adding a diagonal. Figure.3 shows a rendered triangle polygon mesh of the depth image given in Figure.2.

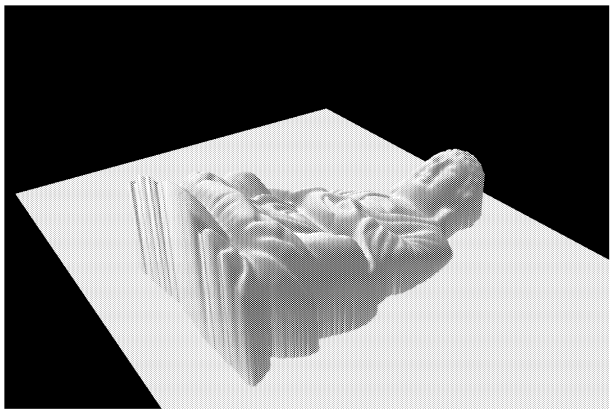


Figure 3: Rendered triangle polygon mesh

Proxy Graph Algorithm

We use a proxy graph algorithmWalker and Salisbury (2003) to calculate the contact force when pointer collides with the polygon mesh.

The proxy graph algorithm always updates the position of the proxy to the endpoint of the haptic device. When the goal is in a free space, proxy is updated directly to the position of goal. When the haptic endpoint penetrates into the polygon mesh, the proxy is updated to the nearest vertex to the goal on the polygon mesh.

Haptic Rendering

We assume that there is a virtual spring connected between the proxy and the endpoint of the haptic device (Figure.4). Thus the contact force F can be calculated with Equation.1.

$$F = K \cdot s + B \cdot v \tag{1}$$

$$s = P - G \tag{2}$$

In this equation, K is the virtual stiffness, B is the virtual damping of the polygon mesh which could be pre-defined by user. They could also be calculated with the color-force parameter mapping introduced in our previous researchesLiu et al. (2010)Takahama et al. (2011) if we have the texture image. The color-force parameter mapping is a method calculating virtual stiffness K and virtual damping B from color information. s is the distance from proxy to haptic endpoint, thus we have $s = P - G$ where P is the proxy and G is the goal, also known as haptic endpoint.

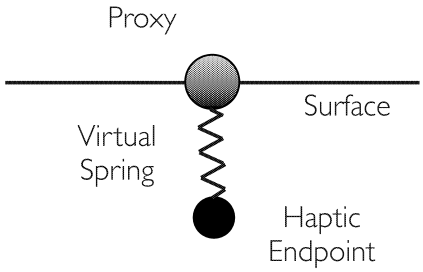


Figure 4: Virtual spring connects between proxy and haptic endpoint

Deformation of Depth Images

We have confirmed that deformation is very effective for improving user experience in haptization systems. Besides the haptic feedback, adding a visual feedback will help increasing the user experience of interaction.
There are several methods for modeling volume deformation which can be divided into three main categories: non-physical models, finite element models and mass-spring models.
Although many researches have been done in using finite element methods for real-time volume deformationsBro-Nielsen and Cotin (1996), general application was limited by extensive computational requirements
We think that a non-physical model of deformation will sustain the high quality of haptic feedback while not substantially degrade the user experience.
Non-physical models are parameter-based representations that include splines, patches, and free-form deformations.Gibson and Mirtich (1997)

In this research we propose a simple non-physical model method of local deformation. Local deformation is performed by applying a displacement to the neighbor vertices of the contact vertex. A simulated situation is demonstrated in Figure.5. Neighbor vertices is defined as the vertices which are within a distance of max value d_{max}.
The displacement D of distance d can be calculated with Equation.3. In this equation, s is the distance from proxy to haptic endpoint, thus we have $s = P - G$ where P is the proxy and G is the goal, also known as haptic endpoint.$\delta(d)$ is a function of distance d which satisfies $0 \leq \delta(d) \leq 1$. Figure.6 gives several examples of displacement with different $\delta(d)$. a is the deformation amount that indicates the amount of deformation. We have $0 \leq a \leq 1$, the object never deforms when $a = 0$, and it deforms the most when $a = 1$. Figure.8 is an example of the local deformation with $d_{max} = 10$ and $a = 1.0$, Figure.9 is an example of the local deformation with $d_{max} = 5$ and $a = 0.6$. Figure.7 gives an example of the deformation on simple shape (cone).

$$\begin{aligned} &D(Q,P) = \delta(d(Q,P),a) \cdot s \\ &\forall Q \in M \rightarrow d(Q,P) < d_{max} \end{aligned} \tag{3}$$

$$d(Q,P) = |Q - P| \tag{4}$$

$$\delta(d(Q,P),a) = -a \cdot \cos(\frac{\pi d(Q,P)}{2d_{max}}) \tag{5}$$

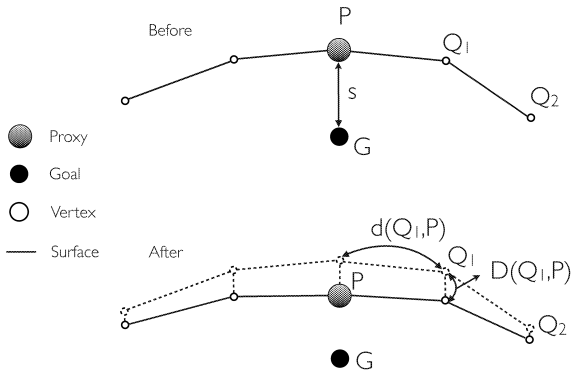


Figure 5: Displacement of the neighbor vertices

Evaluation Experiments

Experiment 1 - System Evaluation

We carried out this experiment with a questionnaire of the operability, sense of space, improvement on contents perception and deformation effects with five-level answers scored from 1 to 5.

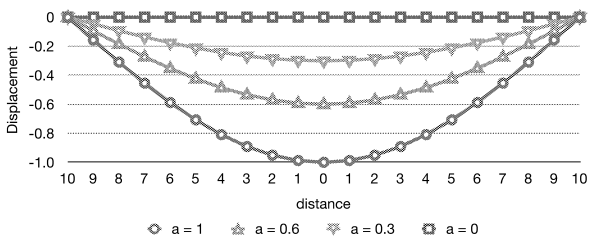
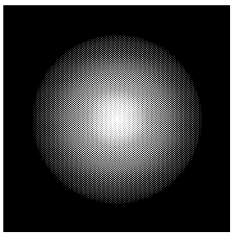
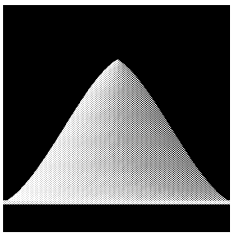


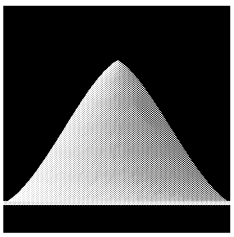
Figure 6: Displacement with different deformation amount



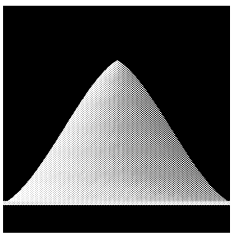
(a) Original depth image of 200 by 200 pixels



(b) Extracted mesh



(c) Local deformation from side of the object with $a = 1.0$, $d_{max} = 10$



(d) Local deformation from side of the object with $a = 0.6$, $d_{max} = 5$

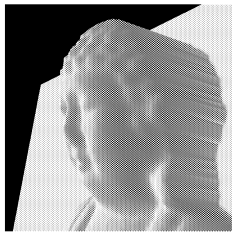
Figure 7: Example of local deformation on a simple shape (cone)

1. Operability
2. Sense of Space
3. Improvement on Contents Perception
4. Deformation Effects

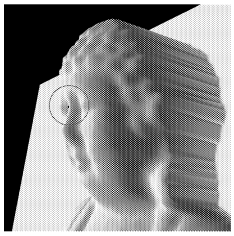
Subjects include 3 expereinced haptic device users and 2 non-experienced users. Regardless of the experience we gave all the subjects a tutorial. There is no time limit. We set the parameters $a = 0.6$, $d_{max} = 5$.
Every subject is required to evaluate the system under all the following three situations: haptization only, deformation only and both haptization and deformation.

Results of Experiment 1

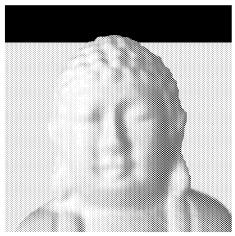
The average results of 5 subjects are shown in Figure.10. The standard deviation of the results are listed in Table.1.



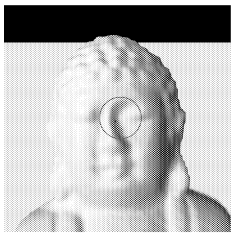
(a) Original



(b) Local deformation from top of the object

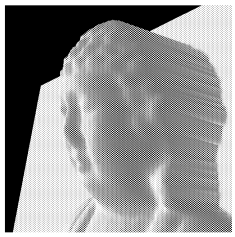


(c) Original

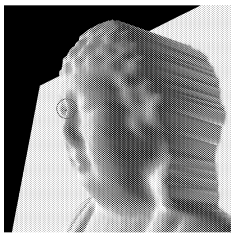


(d) Local deformation from side of the object

Figure 8: Example of local deformation with $a = 1.0$, $d_{max} = 10$



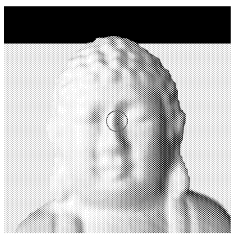
(a) Original



(b) Local Deformation from Top of the Object



(c) Original



(d) Local Deformation from Side of the Object

Figure 9: Example of local deformation with $a = 0.6$, $d_{max} = 5$

- H = Haptization Only
- D = Deformation Only
- HD = Haptization and Deformation

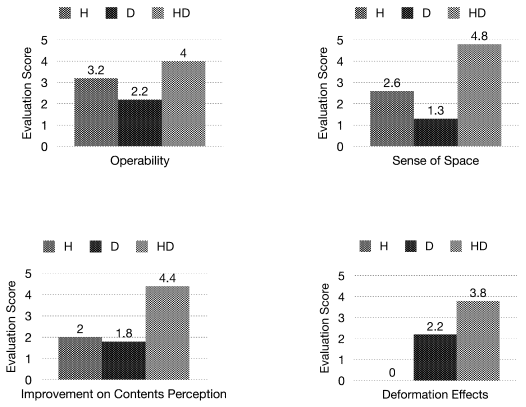


Figure 10: Result of the questionnaire of experiment 1

Table 1: Standard deviation of the results of experiment 1

	H	D	HD
1	1.36	0.40	0.40
2	0.75	0.75	0.63
3	0.89	0.75	0.50
4	N/A	0.75	0.75

Table 2: P-values of students' t-tests of experiment 1

	H and HD	D and HD	H and D
1	0.0175	0.0001	0.1599
2	0.0054	0.0008	0.0341
3	0.0081	0.0004	0.7780
4	0.0004	0.0349	0.0041

Discussion of Experiment 1

Obviously with both haptization and deformation the overall evaluation results are the best. Even in each single evaluation, the result gets higher with both haptization and deformation.
Operability gets very poor with deformation only because the lack of haptic feedback makes the operation of the haptic devices strange. Sense of space gets even poorer with deformation. With haptization only, although The lack of deformation degrades the operability to some extent, the operability is still acceptable. However, with both haptization and deformation, the improvement of the contents perception is confirmed.
By analyzing the statistical significance with students' t-test at a threshold of 0.05, we confirmed significant difference between Group Haptization and Group Haptization and Deformation. We also confirmed the significance between Group Deformation and Group Haptization and Deformation, from which we can draw the conclusion that by combining haptization and deformation we can get better user experience. However, when we compare Group Haptizaion and Group Deformation, the data failed students' t-test on operability and improvement on contents perception, which indicates there are no significant difference between these two groups.

Experiment 2 - Comparision with the Previous Image Haptization System

In order to compare the proposed system with the previous image haptization systemLiu et al. (2010), we carried out experiment 2. This is a questionnaire of the haptization quality, improvement of the contents perception and deformation effects with five-level answers scored from 1 to 5.
The condition of proposed system in experiment 2 is as same as experiment 1. The configuration of previous system is as same as it is described in Liu et al. (2010).
Every subject is required to evaluate the two systems with both haptization and deformation enabled and mark the questionnaire sheet after the experiment.

1. Haptization Quality
2. Improvement on Contents Perception
3. Deformation Effects

Results of Experiment 2

The average results of 5 subjects are shown in Figure.11. The standard deviation of the results are listed in Table.3.

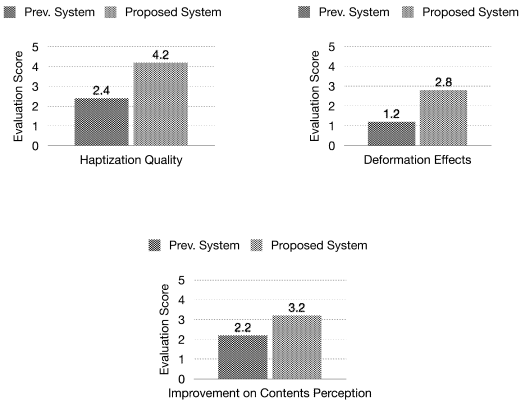


Figure 11: Result of the questionnaire of experiment 2

Table 3: Standard deviation of the results of experiment 2

	Prev. System	Proposed System
1	0.49	0.75
2	0.40	1.17
3	0.75	0.75

Table 4: P-value of the students' t-test of experiment 2

	P-value
1	0.0086
2	0.0349
3	0.0341

Discussion of Experiment 2

From the average of the results we find that the proposed system got a higher score in each single evaluation. We also confirmed the significance of the results as the data passed the students' t-test with a threshold of 0.05, which suggested depth image haptization and deformation has better haptization quality, deformation effects and user experience than previous image haptization system.

Conclusion

We proposed a depth image haptization system with local deformation. A triangle polygon mesh is extracted and built from the depth image for the haptic rendering. A proxy graph algorithm is used to calculate the contact force between the contents and the user's finger. Local deformation is applied by moving the corresponding vertices towards the vector of proxy and endpoint.
We have known that adding local deformation to the dpeth image haptization improved the user experience and perception of the image contents in the proposed system through the results of experiment 1.
Results of experiment 2 suggest that depth image haptization and deformation has better haptization quality, deformation effects and user experience than the previous image haptization system.

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