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Representational Fidelity in Distributed and Remote Lab Environment

Students today lack the real experiences needed to make sense of complex technical concepts although industry is one of the primary customers that constantly challenges academia to make curricula more relevant to professional practice. Our response to these influences was to create and test idea of Distributed and Remote Lab dedicated to active learning. In this survey, the experiments on representational fidelity measures are performed on two types of "client" user interface (Wall and Window) in two modes of presentation (Desktop and Video beam) of the distributed manufacturing system. The proposed remote system has allowed students from Belgrade, Serbia to dynamically interact with a real manufacturing process held in Minho's Lab, Portugal, to carry out a remote experimental practice. This survey gives advantage to Wall interface, in the fields of smooth display of view changes and object motion and consistency of object behaviour. There are also weaker correlations between representational fidelity measures when Wall interface is used and certain advantage on desktop presentation mode.

Keywords: *Distributed and Remote Lab environment, Representational Fidelity, Remote Control, User Interface*

1. INTRODUCTION

Recent developments of hardware, software, Web-based technologies and computer graphics technologies, provided tremendous capabilities in development and implementation of Remote Control [1]. On other side, nowadays, the importance of practical experiences for the development of competences in engineering is extremely important. Industrial and Manufacturing Engineering subjects are always greatly improved when classroom teaching is supported by adequate laboratory courses and experiments following the "learning by doing" paradigm, which provides students a deep understanding of theoretical lessons. However, expensive equipment and limited time often prevent teachers having sufficient educational platforms for students [2]. The logical artefact for an Industrial and Manufacturing Engineering curriculum would be a real-world factory. However, students would not be able to apply any of their concepts to a realworld factory and see the effect of the changes made. Also, the logistical problems in providing sufficient student access to a factory would be daunting. To achieve the advantages of a real-world factory environment for the students with the logistical and other problems using an actual Distributed and Remote Lab Environment concept could be a solution.

This paper refers to the new direction for teaching in Industrial and Manufacturing Engineering field. This survey offers and examines in details one of aspects in the concept of Distributed and Remote Lab environment - representational fidelity. Also, whether is used in academic courses on campuses or in training courses within enterprises, distance education is a very effective learning method.

2. DISTRIBUTED AND REMOTE LAB ENVIRONMENT

2.1 Distributed and Remote Lab Environment Concept

Students today lack the real life experiences needed to make sense of complex technical concepts since industry is one of the primary customers of the universities. Those customers are constantly challenging academia to make curricula more relevant to professional practice. Most degree programs devote the bulk of their credit hours to engineering science fundamentals and do a better job of preparing students for graduate study than for industrial practice. According to Whitman [3] curricula still show poor retention of basic concepts, limited transfer of knowledge from previous courses and little integration of process knowledge and analysis tools.

On the other side, according to Scapolo [4] manufacturing enterprises in 2020 should bring new ideas and innovations to the market place rapidly and effectively. Individuals and teams should learn new skills rapidly because of advanced network-based learning, computer-based communication across extended enterprises, enhanced communications between people and machines, and improvements in the transaction and alliance infrastructure. Collaborative partnerships should be developed quickly by assembling the necessary resources from a highly distributed manufacturing capability in response to market opportunities and just as quickly dissolved when the opportunities dissipate.

In recent years, new findings in cognitive processes and behavioural psychology have demonstrated the limits of lecture, and alternatives to augment its

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effectiveness have been demonstrated, including laboratories and collaborative learning. Numerous studies have demonstrated that active, collaborative, problem-based learning are superior to traditional lecture-based methods [5,6,7,8]. Reviews of nearly a hundred studies comparing lecturing with other methods [9] have found that: unsupervised reading is better than lecturing; lectures are quite ineffective for stimulating higher-order thinking; lectures cannot be relied on to inspire students; and the attention span of students in lecture can be maintained for about 10 to 15 minutes, after which learning drops off rapidly.

On other side, the synergy of networking and communication channels is an essential factor in communicating and coordinating the activities of engineers in enterprises dispersed in different locations that enables the free capacities of small production systems to be used by network members/clients anywhere and anytime they are free, making the manufacturing system ubiquitous [10].

Our response to these influences was to create Distributed and Remote Lab dedicated to active learning that could be industry-partnered. The Distributed and Remote Lab is a paradigm shift to interdisciplinary, real-world problem solving in engineering education.

The Distributed and Remote Lab is founded on four beliefs: (1) lecturing alone is not sufficient; (2) students benefit from interactive hands-on experiences; (3) experiential learning involving student knowledge sharing is always beneficial and (4) industrial practice experience enriches the educational process and provides tangible benefits to all.

Namely, the Distributed and Remote Lab environment for network based sustainable university partnership is a tool for new generation of education to enhance new jobs creation in manufacturing sector with low level investment and increase value added in manufacturing, promoting higher level of products and services, internationalisation through networking, the contribution to the knowledge based economy and, at the end, to target environmental effects.

2.2 User interface for Distributed and Remote Lab

It is well known that in a contemporary manufacturing system, effective human communication is vital, not only for its operation, but also for its design and any further developments and changes [11]. New communication channels are described in detail in [12], giving attention to human operator and remote cell. One of those channels, i.e. the human - machine communication channel, is discussed in detail in [1].

The user interface for the remote controlling functionality, as described in [1], has several key components, namely: 1) control panel for remote machine controls (for e.g. to move axes, start/stop spindle, upload and run a machine program etc.) 2) communications controls 3) panel to see absolute and relative positions of each axis, i.e. the feed-back information from the machine movements, and 4) video frame to get live video feeds. From the user viewpoint, usability and collaboration are very important measures of user interface [10]. Usability comprises effectiveness, efficiency and representational fidelitymeasures, while collaboration includes collaboration effort, awareness/involvement and copresence [10].

In this survey, the experiments are performed on the "client" user interface of the distributed manufacturing system which belongs to the Ubiquitous Manufacturing System Demonstrator [13]. Two distinct types (versions) of this user interface were examined to see which one better fits Learning Factory Environment: 1) Window and 2) Wall Interface. The remote user or the "client" operates on a remote cell [12] while simultaneously receiving live video feedback as well as CNC machine status feedbacks [1]. Both versions of user interfaces had two modes of presentation - computer desktop screen and video beam presentation, to check which one fits better proposed distance learning concept.

Our experiment involved 68 participants, students at Industrial Engineering Department at Faculty of Mechanical Engineering, University of Belgrade, Serbia, that have used the interface for remote collaborative control of manufacturing systems to control of CNC machine that is located at the laboratory at Universidade Minho, Guimarães, Portugal. The experiment was conducted in the laboratory at Faculty of Mechanical Engineering in Belgrade, Serbia.

(a) (b)

Figure 1. Different types of used interfaces used on computer desktop screen and using video beam presentation, (a) – Window Desktop, (b) Wall Video beam

2.3 Representational Fidelity of User interface for Distributed and Remote Lab Environment

Many authors have stressed the importance of immersion and presence, suggesting that they are critical features distinguishing virtual environments from other types of computer applications, defining presence as the subjective sense of being in a place and immersion as the objective and measurable property of the system or environment that leads to a sense of presence [14,15,16,17]. Authors in [18] are looking more closely at the immersive properties of an environment, and argue that the fidelity of the representation, along with the types of interactivity available within the environment, lead to a high degree of immersion and consequently to a strong sense of presence.

Our perspective also is that representational fidelity and learner interaction are the most important characteristics of distributed and remote environment, whereas construction of identity, sense of presence and co-presence are characteristics of the learner's experience as a result of these environment characteristics.

Representational fidelity measures that are going to be explored in this survey (explained in detail in [18]), in aim to help in further development of distributed and remote environment include:

- Realistic display of environment - RDE
- Smooth display of view changes and object motion - SDM
- Consistency of object behaviour - COB and
- User representation – URE.

3. METHODOLOGY AND RESULTS OF REPRESENTATIONAL FIDELITY EVALUATION

The experiment involved 68 students that, from Belgrade, Serbia, have controlled CNC machine located in Minho, Guimarães, Portugal. The task consisted of connecting to the remote cell, starting a CNC machine, uploading a g-code CNC program to conduct operations on the machine, remotely using the emergency stop button, which exists physically on the CNC machine, moving axes, assess the status of the machine and real-time positions of the axes. Wall interface, oposite to Window type, had added spindle button that allows the client to start/stop spindle to make any holes/cutting using the machine tool. After that, they have filled out questionnaire with 1-5 Likert scale to express their feelings about all types of interfaces and presentation modes used. Data collected descriptive statistics (mean values, median, standard deviation and coefficient of variation) about representational fidelity features are shown in Table 1.

After that, data collected are examined using either Student t-test for parametric variables or Mann-Withney U* test for nonparametric variables to test relationship for certain variables [19]. Further comparison was conducted by linear regresion correlation coefficients or by Spearman rank test, depending of variable characteristics (parametric or non parametric).

Conducted test has proved that there is no difference in realistic display of environment between use Wall or Widow interface. The same conclusion can be derived for usage of type of presentation - desktop or video beam (Table 2).

Table 1. Descriptive statistics

Variable		Mean	Median	SD	cv (%)
RDE	Wall D	3.956	4.00	0.905	22.88
	Wall V	4.088	4.00	0.926	22.65
	Window D	3.882	4.00	0.923	23.77
	Window V	3.897	4.00	0.917	23.52
SDM	Wall D	4.074	4.00	1.041	25.56
	Wall V	4.074	4.00	1.041	25.56
	Window D	4.059	4.00	1.063	26.20
	Window V	4.029	4.00	0.962	23.86
COB	Wall D	4.221	4.00	0.844	19.99
	Wall V	4.250	4.00	0.853	20.07
	Window D	4.147	4.00	0.902	21.75
	Window V	4.279	4.00	0.844	19.72
URE	Wall D	4.265	4.50	0.857	20.10
	Wall V	4.309	4.00	0.738	17.13
	Window D	4.176	4.00	0.929	22.25
	Window V	4.221	4.00	0.844	19.99

Table 2. Realistic display of environment testing - RDE (WA- Wall, WI- Window, D- desktop, V- Video beam)

			p-value	remark
RDE WA D	=	RDE WI D	n.s.	
RDE WA V	=	RDE WI V	n.s.	
RDE WA D	=	RDE WA V	n.s.	
RDE WI D	=	RDE WI V	n.s.	
RDE WA	=	RDE WI	n.s.	
RDE D	=	RDE V	n.s.	

Smooth display of view changes and object motion is absolutely better in Wall comparing to Window interface. This difference does not exist between Wall and Window interface regarding usage of desktop or video beam presentation (Table 3).

Table 3. Smooth display of view changes and object motion - SDM (WA- Wall, WI- Window, D- desktop, V- Video beam)

			p-value	remark
SDM WA D	=	SDM WI D	n.s.	
SDM WA V	=	SDM WI V	n.s.	
SDM WA D	=	SDM WA V	n.s.	
SDM WI D	=	SDM WI V	n.s.	
SDM WA	>>>	**SDM WI**	**0**	***
SDM D	=	SDM V	n.s.	

Consistency of object behaviour has absolute advantage in Wall comparing to Window interface, in all aspects of testing, overall, in use of desktop or video beam. Also desktop presentation has absolute advantage in use comparing to video beam, regardless of type of used interface (Table 4).

Table 4. Consistency of object behaviour - OB (WA- Wall, WI- Window, D- desktop, V- Video beam)

			p-value	remark
COB WA D	>>>	**COB WI D**	**0**	***
COB WA V	>>>	**COB WI V**	**0**	***
COB WA D	>>>	**COB WA V**	**0**	***
COB WI D	>>>	**COB WI V**	**0**	***
COB WA	>>>	**COB WI**	**0**	***
COB D	>>>	**COB V**	**0**	***

Estimate of user representation including control, maneuver and manipulation of the object, is significantly better when Wall is used comparing to Widow interface (Table 5). The same results are obtained when working on desktop presentation mode in comparison to video beam. Exception is the use of desktop, where there no influence of type of interface.

Table 5. User representation - URE (WA- Wall, WI- Window, D- desktop, V- Video beam)

			p-value	remark
URE WA D	=	URE WI D	n.s.	
URE WA V	>>>	**URE WI V**	**0**	***
URE WA D	>>>	**URE WA V**	**0**	***
URE WI D	>>>	**URE WI V**	**0**	***
URE WA	>>>	**URE WI**	**0**	***
URE D	>>>	**URE V**	**0**	***

Further examination included interrelations between representational fidelity measures whose final results are presented in Tables 6 and 7.

Table 6. Representational fidelity measures for Wall interface (D- desktop, V- Video beam)

WALL	RDE WA D	RDE WA V	SDM WA D	SDM WA V	COB WA D	COB WA V	URE WA D	URE WA V
RDE WA D	X	X	**	X	***	X	X	X
RDE WA V	X	X	X	X	X	***	X	***
SDM WA D	**	X	X	X	***	X	X	X
SDM WA V	X	X	X	X	X	***	X	**
COB WA D	***	X	***	X	X	X	***	X
COB WA V	X	***	X	***	X	X	X	***
URE WA D	X	X	X	X	***	X	X	X
URE WA V	X	***	X	**	X	***	X	X

Measured correlations lead to the following conclusions. Realistic display of environment (RDA) with Wall interface and desktop presentation is in direct correlation with consistency of object behaviour, and there also exists strong interrelationship with the smooth display of view changes and object motion. RDA with video beam presentation is in direct correlation with consistency of object behaviour and user representation.

Smooth display of view changes (SDM) and object motion with Wall interface and desktop presentation is directly correlated with consistency of object behaviour. In addition, there is a strong correlation with RDE. SDM using Wall interface with video beam presentation is in direct correlation with consistency of object behaviour, and there also exists strong relationship with user representation.

User representation (URE), i.e. estimate of user representation which include control, maneuver and manipulation of the object, with Wall interface and desktop presentation is in direct correlation with consistency of object behaviour.

URE using Wall interface and video beam presentation is in direct correlation with RDE and COB, while there also exists strong correlation with SDM.

Consistency of object behaviour using Wall interface with both desktop and video beam modes of presentation is directly correlated to RDE, SDM and URE.

Table 7. Representational fidelity measures for Window interface (D- desktop, V- Video beam)

WINDOW	RDE WI D	RDE WI V	SDM WI D	SDM WI V	COB WI D	COB WI V	URE WI D	URE WI V
RDE WI D	X	X	*	X	X	X	X	X
RDE WI V	X	X	X	*	X	***	X	***
SDM WI D	*	X	X	X	*	X	X	X
SDM WI V	X	*	X	X	X	***	X	***
COB WI D	X	X	*	X	X	X	*	X
COB WI V	X	***	X	***	X	X	X	***
URE WI D	X	X	X	X	*	X	X	X
URE WI V	X	***	X	***	X	***	X	X

Realistic display of environment with Window interface and desktop presentation is correlated with SDM. When using the video beam presentation there is absolute correlation with COB and URE. Furthermore, there exists correlation with SDM.

Smooth display of view changes and object motion with Window interface and desktop presentation is in correlation with RDE and COB. In case when video beam presentation, there is direct correlation with COB and URE, while correlations exist with RDE.

Consistency of object behaviour using Window interface and desktop presentation shows correlations with SDM and URE. When using video beam presentation absolute correlation exists with RDE, SDM and URE.

User representation (URE), i.e. estimate of user representation which includes control, maneuver and manipulation of the object, with Window interface and desktop presentation indicates correlation with COB. In case when video beam presentation is used there exists absolute correlation with RDE, SDM and COB.

4. CONCLUSIONS AND PROPOSAL FOR FURTHER RESEARCH

Distributed and Remote Lab idea is aimed to help:

• cross-university course development process and sharing of knowledge using modern facilities for production realization settled in one place;
• student participation in course development;
• use of the World Wide Web for information dissemination;
• student training classes in basic manufacturing skills regardless of place where equipment is placed;
• integrated curricula between universities;
• picture Tel video conferencing between students, industry and universities and
• cross-university, cross - countries students projects based on real industrial problems.

The proposed remote system has allowed students to dynamically interact with a real process to carry out a remote experimental practice, guaranteeing the availability of lab resource to be accessed. In our previous surveys [1,10] is proved that the "Wall Interface" type user interface is easier for work. On the technical side, in the Wall type interface there is a slight delay of information feedback/transmission and that in further development could be corrected. This survey again gives advantage to "Wall Interface", in the fields of smooth display of view changes and object motion and consistency of object behaviour as representational fidelity measures. There are also weaker correlations between representational fidelity measures when "Wall Interface" is used. This survey also gives certain advantage to desktop presentation mode, when it is statistically significant.

Proposal for further research is students' team work testing in Distributed and Remote Lab (in a small groups with 2 or 3 participants). Also an evaluation test to measure the usefulness of the real lab in comparison to the remote lab is possible to be designed and implemented. Concerning future work perspectives, an ambitious scope is also to achieve the integration of new control processes for remote operation in order to share these resources in the network.

Final aim could be Learning Factory Lab environment, for network based sustainable university-industry partnership aimed to encourage the use of integrated virtual reality models of manufacturing systems to design, improve and operate these systems, teach the workforce (students as well as industrial personnel) to understand the systems they work with and to serve as intelligent initiators and partners for change by providing a state-of-the-art, hands-on active learning laboratory, practice-based curriculum and real, industry-driven projects.

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NOMENCLATURE

RDE	Realistic display of environment
SDM	Smooth display of view changes and object motion
COB	Consistency of object behaviour
URE	User representation
Wall D	Wall interface, Desktop display
Wall V	Wall interface, Video beam display
Window D	Window interface, Desktop display
Window V	Window interface, Video beam display
RDE WA D	Realistic display of environment, Wall interface, Desktop display
RDE WA V	Realistic display of environment, Wall interface, Video beam display
SDM WA D	Smooth display of view changes and object motion, Wall interface, Desktop display
SDM WA V	Smooth display of view changes and object motion, Wall interface, Video beam display
COB WA D	Consistency of object behaviour, Wall interface, Desktop display
COB WA V	Consistency of object behaviour, Wall interface, Video beam display
URE WA D	User representation, Wall interface, Desktop display
URE WA V	User representation, Wall interface, Video beam display
RDE WI D	Realistic display of environment, Window interface, Desktop display
RDE WI V	Realistic display of environment for Window interface and Video beam display
SDM WI D	Smooth display of view changes and object motion, Window interface, Desktop display
SDM WI V	Smooth display of view changes and object motion, Window interface, Video beam display
COB WI D	Consistency of object behaviour, Window interface, Desktop display
COB WI V	Consistency of object behaviour, Window interface, Video beam display
URE WI D	User representation, Window interface, Desktop display
URE WI V	User representation, Window interface, Video beam display
SD	standard deviation
cv (%)	coefficient of variation
p - value	p - level of significance for tested variables
n.s.	not significant
remark	significant at $p<0.05$(*), at $p<0.01$ (**), at $p<0.001$(***)

РЕПРЕЗЕНТАТИВНА ТАЧНОСТ У ОКРУЖЕЊУ ДИСТРИБУИРАНЕ ДАЉИНСКИ УПРАВЉАНЕ ЛАБОРАТОРИЈЕ

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Студентима данас недостају реална искуства о комплексим техничким концептима упркос чињеници да индустрија, као примарни корисник, стално указује академској зајединици на потребу и значај реалног практичног искуства. Наш одговор на то је креирање и тестирање Дистрибуиране даљински управљане лабораторије посвећене активном учењу. У овом истраживању, спроведени су експерименти о репрезентативној тачности за два типа корисничких интерфејса (Wall and Window) са два вида презентације (на десктоп рачунару и путем видео бима). Предложен систем даљинског управљања омогућио је студентима из Београда, Србије динамичку интеракцију са реалним производним процесом у лабораторији у Мињу, Португал. Ово истраживање даје предност Wall интерфејсу, на пољу јасноће померања и доследности понашања објекта. Код Wall интерфејса постоје слабије корелације између мера репрезентативне тачности, а одређену предост треба дати и десктоп виду презентације.