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Human - Computer Interactions and User Interfaces for Remote Control of Manufacturing Systems

This paper refers to the new direction for enhancement in traditional remote controlling functionality in manufacturing systems. Employing a diversity of tools such as videoconferencing, computer supported cooperative work tools, immersive virtual reality, virtual environment tools, such as "Metaverse" tools, and Internet through Pragmatic Web, is necessary for overcoming the "space barrier". Therefore, further analysis of human-machine user interface is crucial for user interaction with manufacturing systems through remote control. That is the motivation for investigation on evaluation of the user interfaces for remote control of manufacturing systems within the above-mentioned framework. Preliminary results of the evaluation of two types of interfaces are presented in this paper. These two interfaces are distinctive in one particular presentational aspect, while all the remote controlling functionalities are equal for both. The results show that one user interface type clearly fares better than the other over a number of factors as graded by users.

Keywords *Manufacturing system, Remote Control, User Interface, Remote Client, User Interfaces Evaluation.*

1. INTRODUCTION

Recent developments of hardware as well as software, including significant lowering the hardware costs, increase of the hardware variety, and networking, i.e. Web-based technologies and computer graphics technologies, provided tremendous capabilities in development and implementation of Remote Control. On the other side, the requirements for sustainability, economic, environmental and social, are “forcing” the research community in developing and implementing new technologies that satisfy them, within which the Remote Control represents one of the instruments that significantly contributes to all of the three sustainability dimensions. Within the framework of the Remote Control user interfaces represent “channels” for human-computer interaction and, consequently, one of the factors of effective and efficient employment and use of the Remote Control.

This paper refers to the new direction for enhancement in traditional user interface designs for remote controlling functionality in manufacturing systems. Therefore, further analysis of human-machine user interface is crucial for user interaction with manufacturing systems through remote control. Preliminary results of the evaluation of two types of interfaces are presented in this paper. These two interfaces are distinctive in one particular presentational aspect, while all the remote controlling functionalities are equal for both. The results show that one user interface type clearly fares better than the other over a number of factors as graded by users.

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2. HUMAN - COMPUTER INTERACTIONS AND USER INTERFACES FOR REMOTE CONTROL OF MANUFACTURING SYSTEMS

2.1 Remote Control of Manufacturing Systems

Globalization and the accompanying technological innovation today encouraged the trend of diversification of market demand. Its dynamism is increasingly difficult long-term planning activities and introduced new conditions for competitiveness, particularly agile and flexible production environment.

In addition, it becomes apparent that an independent company is no longer capable of independent performance in the market respond to new circumstances in which it is developing.

Traditional ways of collaborating companies in stable supply chains, based on long-term partnerships are not sustainable in the circumstances of today's global economy. For the next generation of engineering environments, the concept of a remote engineering system provides a new approach and strategy to enhance their competitive advantages;and it also provides a fast, economical and experience sharing method for the enterprises [1]. On the other side, organizations today are flatter, have a more diverse employee base and a greater use of teams [2]. The workforce is constituted of employees who reflect differences in age, ethnic heritage, race, physical abilities, gender and sexual orientation [2,3]. Proposals for new measures of usability are also continuously emerging [4]. The human-computer interfaces literature contains discussions of new dimensions such as aesthetics [5], apparent usability [6], sociability [7], and flow [8].

These proposals all seem to suggest that common conceptions of how to measure usability today need revisiting with special attention paid to these and other emerging issues, in our opinion. The fact is 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 [2,3]. The synergy of networking and multimedia technologies is adopted in communicating and coordinating the activities of the engineers of a multinational enterprise dispersed in different locations, using computer supported cooperative work.

New communication channels should enable overcoming the full interoperability barriers of the space and time, i.e. employing a diversity of tools such as, videoconferencing (VC), computer supported cooperative work (CSCW) tools, virtual reality (VR) and especially immersive virtual reality (IVR), other virtual environment (VEnv) tools, such as "Metaverse" tools, and Internet through Pragmatic Web, for overcoming the "space barrier", and e.g. ubiquity of resources through UMS (Ubiquitous Manufacturing Systems), for overcoming the 'time barrier'. The communication channels should enable the generative integration process life-cycle, i.e. the phases of integration synthesis, operation and termination [9, 10].

The above mentioned communication channels have been discussed in [11], in the form of a "prototype multiplex communication system" where the multiple communication channels are between human operator and remote cell. One of those channels, i.e. the human – machine communication channel, representing the basic architectural pattern for remote control of more complex systems, is what concerns the current investigation. This communication channel is drawn in the Figure 1.

2.2 Functional Representation of Remote Control User interface

Therefore, for the presented work, only the user interface concerning only this communication channel is discussed, in the form of analysis of human-machine user interface for user interaction in remote control functionality within a distributed manufacturing systems paradigm. That is the motivation for investigation on evaluation of some aspects of the user interfaces implementations for remote control of manufacturing systems within the above-mentioned technological and functional framework.

In Figure 2, a functional representation of the above discussed user interface for remote control of manufacturing system is given. The diagram in Figure 2 is purely functional and is for the purpose of showcasing functional components and properties of the user interface in the current investigation.

As it is visible in the Figure 2, the user interface for the remote controlling functionality has several key components, namely: 1) control panel for remote machine controls (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. The last component, video frame, is the major elementof the subsequent analysis in the presented work.

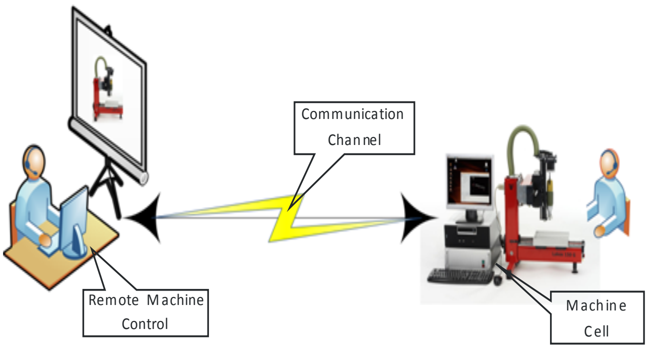

Figure 1. Human – Machine Communication channel for remote control

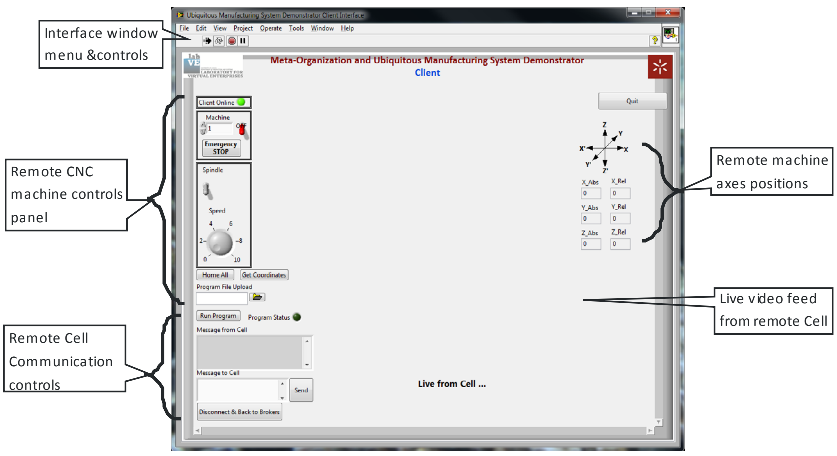

Figure 2. Functional Presentation of Remote Control User Interface

2.3 Two types of user interfaces

In this work, the experiments are performed on the "client" user interface of the distributed manufacturing system which belongs to the Ubiquitous Manufacturing System Demonstrator [12] as described in the previous publication. For the present investigation, two distinct types (versions) of this user interface were implemented. Both of these user interfaces provide the same type of controls for controlling Remote CNC machining.

Due to their distinctive features, the two interfaces are named characteristically: 1) Window Interface and 2) Wall Interface. The remote user or the "client" operates on a remote cell [11] while simultaneously receiving live video feedback as well as CNC machine status feedbacks.

The "Window Interface", as shown in Figure 3, is an implementation of the remote control "client" user interface of Figure 2. And it is so called because the live video feed from the remote cell is shown inside a window panel on the interface, as if the human "client" operator is watching the remote cell through a window while controlling the remote CNC machine(s).

The whole interface looks like a window on the computer screen. The "Window interface" shows a "traditional" user interface where various interface components are organized in their separate panels, giving a typical "dashboard" style command and view window of a computer screen interface.

The user gets the desired sense of remotely controlling the CNC machines while working on a computer connected through the Internet or any data network (local area network or wide area network).

The "Wall Interface", in Figure 4., is another slightly different implementation of the user interface of Figure 2. It differs from the "Window Interface" in one feature, that is, it shows the live cell video feedback not in a separate window panel but instead in the whole background of the user interface.

Also, in this implementation of the software, the interface window is maximized, by default, and it occupies the whole desktop (computer) screen, as if there is no window but the "wallpaper" of the computer, hence the "Wall Interface" name.

Figure 3. "Window Interface" of Remote Client for Operations on Cell

Figure 4. "Wall Interface" of Remote Client for Operations on Cell

Another deliberate interpretation of the "Wall Interface" is related to how the user uses it. Consider viewing this interface not only on the computer screen, but projecting it on a wall. This gives a real-time life-size live picture of the remote cell as if being in that cell physically and operating on the object piece controlling the machine tool. This clearly gives the two remotely located entities (remote user – "client", cell operator and cell machines) an ability of remote operation as well as two-way multiplex communication [11], which is absent in the traditional models.

This distinction between the two interface implementations is the object of the hypothesis of this investigation. The objective is to provide virtual presence to the remote user ("client") operating the remotely located CNC machines, breaking the "space' barrier in the process. And it is evaluated by calculating the "performance measures" as given in the next section.

3. METHODOLOGY AND RESULTS OF USER INTERFACES EVALUATION

The experiment involved 68 subjects, students at Faculty of Mechanical Engineering, University of Belgrade, Serbia, as representatives of future users of the interface for remote collaborative control of manufacturing systems. Their average age is 23.07 years. The experiment was conducted in the laboratory at Faculty of Mechanical Engineering in Belgrade, Serbia. The task was the control of CNC machine that is located at the laboratory at Universidade 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 had added spindle button that it allows the client to start/stop spindle to make any holes/cutting using the machine tool. Clicking on this button will change the color from transparent to Green, indicating that the Spindle is spinning right now. Click it again to stop spinning. The color should change back to transparent.

Evaluation of parameters of efficiency, effectiveness and satisfaction of respondents with both types ofinterface is implemented as follows. During the experiments on both interface types time to complete task, the percentage of accuracy and the number of errors were measured. After the completion of the experiment respondents' satisfaction with the particular type of interface is evidenced in questionnaire with the Likert scale from 1 to 5. According to the recommendations of the [13] 25 to 50% of the questions were recoded (set in the opposite direction in relation to other issues) in this study was done recoding 30% of questions.Both interfaces are evaluated with high marks from respondents.

Respondents have answered that interface type Window provides less information than the wall (2.08 compared to 1.706). They find that control on Window is more difficult than on the Wall interface (1.6029 compared to 1.5735). We also find more information in late on window interface (2.08 versus 1.93). Number of errors made whileremotely controlling the CNC machine is the same with both, Window and Wall, interfaces, with a higher standard deviation of the Window interface. The operating time is longer on the Wall interface than the Window (2.735 compared to 2.559). Respondents felt that a realistic view of the surrounding is better in Wall interface (3.9559 to 3.8823). The mental effort invested is somewhat higher in the Wall than Window interface (1.8676 to 1.8529), as well as the consistency of object behavior (4.2206 to 4.1471). Percent of task realization of the task is greater on the Wall at than the Window interface (4.5294 compared to 4.5147), while the accuracy of the both types is around 4.56. The characteristics of respondents and the results (mean and standard deviation) are given in Tables 1 and 2.

The first of all descriptive statistics calculation is necessary to confirm which interface type is better, as shown in Table 3. for an example of "The interface provides little information". There is greater median then mean difference.

Table 3. Descriptive statistics for variable "The interface provides little information"

	N	Mean	Median	SD	Cv (%)
The interface provides little information Wall	68	1.706	1.500	0.865	50.70
The interface provides little information Window	68	2.088	2.000	1.018	48.76

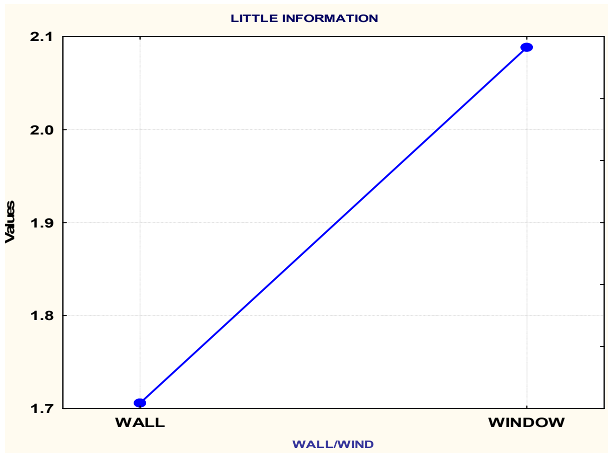

Figure 5. Plot of means for "The interface provides little information" on Wall and Window interface type

Statistical ANOVA testing for the same example is shown in detail on Figure 5 and in Table 4. As can be seen ANOVA testing shows significantly lower values for Wall type of interface then for Window type lower then 0.05 level.

Table 4. ANOVA results for variable "The interface provides little information"

	SS	df	MS	F	p
Effect	4.970588	1	4.970588	5.5696	0.0199*
Error	119.5882	134	0.892450		
Total	124.5588	135			

In case of comparision of the delay of informations, at least for one parameter coefficient of variation was greater than 30% or the median test for signs showed that the median is significantly different from the sample mean. Therefore, U* Mann-Whitney's test was used. Results indicate (Table 5.) that Wall type has highly significantly smaller delay of information then Window type of interface.

Table 5. Mann-Whitney U*- test results for variable "Information delay"

Variable	Rank Sum	U*	z	p-level
Window	861	0.00	-4.1918	0.000
Wall	315			

4. DISCUSSION OF THE RESULTS AND PROPOSAL FOR FURTHER RESEARCH

Accuracy (and number of errors made in operations) is equal on both the proposed types of interface for remote control of production systems. However, the results show that despite the fact that the participants are accustomed to work in the surrounding closer to window type of interface, which is reflected in their conducting of the tasks faster, with less mental effort. Other measures of satisfaction and efficiency suggest that for remote collaborative control of production systems should be further developed with Wall type of interface, because as is clearly seen from the results demonstrated in the previous section the "Wall Interface" type user interface is easier for work, offering smaller information delay and with greater representational fidelity. 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. Further studies with the stronger statistical analysis to confirm the hypothesis will be done soon.

Proposal for further research is also for the analysis of both types of interface on different screen size - tablet, desktop and video beam and analysis of parameters in individual and group work. As found in the investigation, surveyed respondents mentioned that they preferred to work in a small group with 2 or 3 participants (mean value 2.64) and that further research may be conducted in that way and also it could be a new factor of research in future works.

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REFERENCES

[1] Tsai, J.P., Kao, Y.C. and Lee, R.S.: Development of a remote collaborative forging engineering system, The International Journal of Advanced Manufacturing Technology, Vol. 19, No. 11, pp. 812-820, 2002.

[2] Putnik, G.D., et al.: Virtual environments for dynamically reconfigurable Concurrent / Collaborative Engineering 'virtual' teams, CIRP Annals-Manufacturing Technology, Vol. 57, No. 1, pp. 171-174, 2008.

[3] De Moor, A. and Weigand, H.: Formalizing the evolution of virtual communities, Information Systems, Vol. 32, No .2, pp, 223-247, 2007.

[4] Hornbæk, K..: Current practice in measuring usability: Challenges to usability studies and research, International journal of human-computer studies Vol. 64, No. 2, pp. 79-102, 2008.

[5] Tractinsky, N.: Aesthetics and apparent usability: empirically assessing cultural and methodological issues, in: *Proceedings of ACM Conference on Human Factors in Computing Systems*, ACM Press, New York, pp. 115–122. 1997.

[6] Kurosu, M. and Kashimura, K.: Determinants of apparent usability, in: *IEEE International Conference on Systems, Man and Cybernetics*, Vancouver, pp.1509–1513, 1995.

[7] Preece, J.: *Online Communities: Designing Usability and Supporting Sociability*, John Wiley and Sons, Chichester, UK, 2000.

[8] Hoffman, D.L. and Novak, T.P.: Marketing in hypermedia computermediated environments: conceptual foundations, Journal of Marketing Vol. 60, No. 3, pp. 50–68, 1996.

[9] Putnik, G.D. and Putnik, Z.: A semiotic framework for manufacturing systems integration–Part I: Generative integration model, International Journal of Computer Integrated Manufacturing, Vol. 23, No. 8-9, pp. 691-709, 2010.

[10] Stamper, R. et al.: Understanding the roles of signs and norms in organizations-a semiotic approach to information systems design, Behaviour & Information Technology, Vol. 19, No . 1, pp. 15-27, 2000.

[11] Shah, V., Putnik, G.D. and Castro, H.: Prototype Multiplex Communication System for Remote Control of Machine Tools, in Putnik. G. D.. Cunha. M. M. (Eds.): *Communications in Computer and Information Science series*, Springer; Heidelberg, Dordrecht, London, New York, Vol. 248,pp. 241-252, DOI: 10.1007/978-3-642-31800-9, 2012.

[12] Putnik, G.D., Shah, V., Castro, H. and Cunha, M.M.: The Functionality of Remote Controlling in Ubiquitous Manufacturing Systems Demonstrator for I*PROMS 'efm'Showcase, Tekhné - Revista de Estudos Politécnicos/Polytechnical Studies Review, Vol 9, No. 15, pp. 169-189, 2011.

[13] Tari, J.J.: Components of successful total quality management, The TQM Magazine, Vol. 17, No. 2, pp. 182-194, 2005.

ИНТЕРАКЦИЈЕ ЧОВЕК-КОМПЈУТЕР И КОРИСНИЧКИ ИНТЕРФЕЈС ЗА ДАЉИНСКО УПРАЉАЊЕ ПРОИЗВОДНИМ СИСТЕМИМА

Весна Спасојевић-Бркић, Горан Путник, Vaibhav Shah, Helio Castro, Зорица Вељковић

Рад приказује нови приступ унапређењу традиционалног даљинског управљања у производним системима заснован на обезбеђењу финкционалности прагматичног нивоа комуникационих канала. Коришћење разноврсних приступа и методологија, попут видео конференције, рачунарски подржаног кооперативног рада, виртуелне стварности, алата других виртуелних окружења, као што су "Metaverse" иИнтернет веб прагматични алати, је неопходно у циљу превазилажења проблема просторне баријере. Стога је даља анализа корисничког интерфејса човек-машина пресудна за интеракцију корисника са производним системом преко даљинког управљања унутар постављених оквира. У овом раду су приказани прелиминарни резултати евалуације два типа коришћених интерфејса, који се нарочито разликују са презентационог аспекта, док су функционалности даљинског управљања исте за оба типа интерфејса. Резултати анализе оцена корисника, показују да је један интерфејс са аспекта корисника, оцењен нивоима различитих фактора, боље од другог.

Table 1. Characteristics of participants in experiment

	Age of the respondent	The average mark score at the faculty	Preferred learning style (1-alone, 2- group)	Computer skills	Ability to transfer knowledge	Desire to meet new software and the like	Optimal group size
Mean	23. 0735	8.2647	1.4411	3.9852	3.5882	4	2.6471
SD	0.7399	0.7399	0.4965	0.7763	0.7323	0.7071	0.9512

Table 2. The results of evaluation of parameters of efficiency, effectiveness and satisfaction of experiment participants

	The interface provides little information	Weight of the hard work	Information delay	Number of errors	Operating time	Invested mental effort	Representational fidelity	The consistency of object behavior	Percentage of task realization	Accuracy of task realization
WALL										
Mean	1.7059	1.5735	1.9264	0.3383	2.7353	1.8676	3.9559	4.2206	4.5294	4.5588
SD	0.8585	1.1921	1.3646	0.6090	0.7787	1.1102	0.8982	0.8374	0.696	0.6726
WINDOW										
Mean	2.0883	1.6029	2.0735	0.3383	2.5588	1.8529	3.8823	4.1471	4.5147	4.5588
SD	1.0108	1.2385	1.4685	0.6776	0.6941	1.0469	0.9160	0.8954	0.735	0.6035