Transdisciplinary Engineering: A Paradigm Shift
C. Chen et al. (Eds.)

doi:10.3233/978-1-61499-779-5-243

A Reference Model to Analyse User Experience in Integrated Product-Process Design

Margherita PERUZZINI[1] Fabio GRANDI and Marcello PELLICCIARI
Dept. Engineering "Enzo Ferrari", University of Modena and Reggio Emilia
via Vivarelli 10, 41125 Modena, Italy

Abstract. The analysis of human factors is assuming an increasing importance in product and process design and the lack of common references for their assessment in industrial practices had driven to define a reference model to analyse the so-called User eXperience (UX) to support human-centred product-process design. Indeed, the recent advances in ubiquitous computing, wearable technologies and low-cost connected devices offer a huge amount of new tools for UX monitoring, but the main open issue is selecting the most proper devices for the specific application area and properly interpreting the collected information content in respect with the industrial design goals. The research investigates how to analyse the human behaviours of "users" (i.e., workers) by a reference model to assess the perceived experience and a set of proper technologies for UX investigation for industrial scopes. In particular, the model has been defined for the automotive sector. The paper defines a set of evaluation metrics and a structured protocol analysis to objectify and measure the UX with the final aim to support the requirements definition in product-process design. The model has been defined to fit different cases: vehicle drivers at work, workers in the manufacturing line, and service operators.

Keywords. User eXperience, Human Factors, integrated product-process design, protocol analysis, digital mock-ups.

Introduction

The Fourth Industrial Revolution is starting to transform the modern companies, but also the way people interact with products and processes due to the change in product smartness as well as the work environments [1] through 2025 and beyond. This technological trend pushes towards the evolution of design, manufacture, operation, and service of products and production systems [2]. Most researches focused on the description of the technological solutions from different points of view (i.e., smart products and connectivity issues, smart machines, IoT applications for industry, cyber-physical systems, embedded technologies to enable product-related services, methods of data acquisition and elaboration, as well as software interface) [3]. Advanced digital and industrial technologies will help people to interact with products and machines, to work better and more efficiently, and return to or be incorporated into the modern manufacturing workforce. Meanwhile, technical developments and interaction

---

[1] Corresponding Author: margherita.peruzzini@unimore.it

technologies among components, machines and people will make the production systems more lean, integrated, agile, traceable, and adaptable [4]. As a consequence, manufacturing enterprises, and in particular "smart factories", will need to consider the socio-technical aspects and to include the assessment of the human interaction into their evaluation. Therefore, the socio-technical transformation towards the smart factory will need new design reference models according to this new "human-centric" perspective focused on the assessment of the so-called User eXperience (UX) [5].
The present research investigates how to analyse the perceived human experience by a reference model for the UX analysis and a technological set-up suitable for industrial scopes.

1. The reference model for UX analysis

1.1. Importance of UX analysis in industrial contexts

Human factors have been recognized as a fundamental aspect in industrial engineering, so that ergonomics is always more often considered in industrial products and systems design. The analysis of human factors is focused on the analysis of the effectiveness and the efficiency with which activities and tasks are carried out, related to both physical and cognitive workload [6]. As far as industrial operations, in different contexts it has been demonstrated that human factors highly affect the global efficiency of industrial processes [7-8]. Indeed, low attention to human factors brings to unnatural positions and dangerous actions executed by workers during their jobs, with consequent lower performances, higher production time, greater absence from work, and a general increase of Musculoskeletal Disorders (MSDs) with a consequence impact on national economies, in Europe as well as in other countries [9].

The term User eXperience (UX) indicates the compendium of reactions and feelings as the combination of physical efforts and stresses with the subjective perceptions (e.g., predispositions, expectations, needs, motivation, mood), which affect human factors and are generated during the interaction between humans and an external system, like a product, a machine or an environment [10]. Such experience depends on the characteristics of the designed system (i.e., complexity, purpose, usability, functionality, etc.), the context of use, and the human factors.

In the industrial context, traditional approaches for the analysis of the human factors are based on the assessment of ergonomic and cognitive performances by observing the users or operators at work and collecting data about their actions, mainly by interviews and video-recorded analysis. In industry, analyses are traditionally focused on posture assessment of physical exposures according to objective methods, such as rapid upper limb assessment (RULA), rapid entire body assessment (REBA), Ovako working posture analysis system (OWAS), or workplace ergonomic risk assessment (WERA) and others [11], while psychophysiological methods, based on monitoring of the human biometrical data like electromyography (EMG), electro-dermal measures, electroencephalography (EEG) or heart rate are not used in industrial contexts. More recently, higher attention to cognitive ergonomics is paid, also thanks to the ISO regulations [12]. Although numerous studies demonstrated the importance of the physical and cognitive stress and their interference, as well as their effects on the human response (with the concept of "strain") [13-14], their analysis in product-process design is still limited. Main researches about cognitive aspects focused traditionally on product design and human-product interaction [15], but they do not explore the new potentialities of smart factories. Indeed, the new enabling technologies offered by IoT and smart systems can support the development of human-product-process symbiosis systems based on real-time data sharing and deep collaboration between the humans and the surrounding environment. This could create a new framework for UX analysis for workers, based on synergistic interactions between humans and machines with the combination of digital and physical worlds. Only recently a structured protocols to assess UX about integrated product-services have been recently proposed an interesting approach [16], but without any integration within smart factory environments.

1.2. The UX analysis reference model for product-process design

The research approach is based on the Norman's model of perception. According to such model, when any human being interacts with an object, a machine or a system, two kind of responses are generally generated: behavioural and cognitive, and information and meanings flow from the user/worker to the product/system in different ways. Such responses automatically occur when a task is accomplished, independently from its type and nature, depending on objective constraints (e.g., posture, duration, task nature, loads, environmental conditions) and subjective conditions (e.g., skills, cultural background, abilities, age, gender). Indeed, anytime a human being performs an action, his/her body and his/her brain generate behaviours and cognitive feedbacks, which respectively affect his/her physical and cognitive workload contributing to the ergonomic performance as well as the cognitive stress. This process characterizes both product interaction and interaction with machines, interfaces and complex systems as generally happens in workplaces. Furthermore, workplaces response is more delicate since it is usually characterized by strong time compression, long execution of tasks, repetitive actions, merged with stressful conditions.

The reference model defined starts from the analysis of the UX generation process and is synthetized in Figure 1. The UX is generated by the exploration of the product-process-system entities, that can be real or virtual, and the stimuli perceived by the "user" by the sensorial and motor channels. As a result, the perceived UX is due to the combination of the physical postures assumed, the executed actions, the mental workload, the subjective impressions, and the perceived usability. According to the Norman's model, three levels of response are generated: behavioural, cognitive and affective. The behavioural response generates the physical workload that is determined by operational comfort, related to physical stress and muscular fatigue, and sematic understanding related to the task comprehension. The cognitive response can be divided into descriptive, associative and intuitive, and refers to the mental stress as combination of numerous causes (e.g., feedback of actions, association, mental mapping, usability, coherence of stimulation, work overload and pressure). Finally, the affective response is linked to the emotional and sensorial perception (e.g., environmental stressors, psychological stressors, life stress, fatigue and sleep disruption). The theoretical bases of such model refer to several models elaborated in literature about human factors analysis and cognitive psychology [17]. The UX analysis is possible thanks to the monitoring of the human response thought different devices, wearable and environmental, able to provide a real-time assessment of the user / worker experience. Two main issues have to be faced at this point: the data collection and the interpretation of the collected data. As far as data collection, a proper UX monitoring set-up has to be chosen according to the product-process nature, the most significant human factors to control, and the company objectives. About data interpretation, a proper protocol analysis has to be defined in order to relate the measured data with a set of assessment metrics. Also in this case, the protocol has to be specific for the company and the scopes of the investigation, but it can be independent from the specific task, the specific worker and the occurring external conditions. The reference model considers also a set of metrics that allows to measure the UX and to relate those metrics with a set of monitoring tools, properly selected according to the investigated area: posture, occlusion, mental load, interaction, and emotions. Their measurement is detailed in the following protocol.

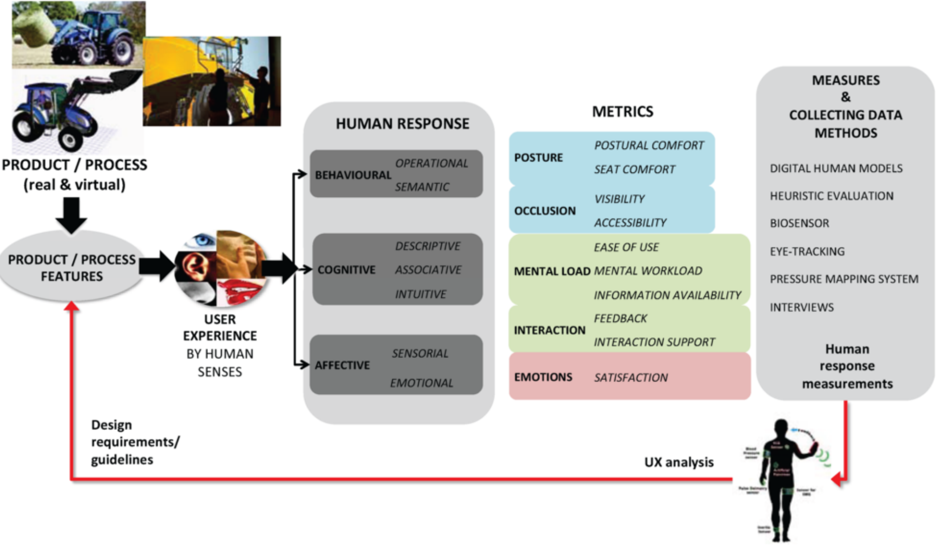

Figure 1. The proposed reference model for UX analysis

Posture assessment is carried out by two assessment metrics:

- *Postural comfort*: it measures the level of comfort perceived by the user as a consequence of the positions assumed and the task executed. It is assessed by analysing human body measures on digital or physical manikins;
- *Seat comfort*: it is applied when tasks require to be seated and measures the comfort perceived by the user as a consequence of the seated positions assumed and the task executed. It is assessed by proper objective methods;

Occlusion assessment is carried out by two assessment metrics:

- *Visibility*: it evaluates how the working space is clearly visible to the user and It is calculated by considering the amplitude of the view cone and analysing the number of obstructions;
- *Accessibility*: it measures whether and how devices and objects involved in task execution are easily accessible from the user, considering the specific body part that should use or manipulate them;

Mental load assessment is carried out by three assessment metrics:

- *Ease of use*: it expresses the effort required to perform a specified task. According to human-machine interaction theories, ease of use is improved by absence of ambiguity, action-driven suggestions offered by the design itself, and limited number of steps required for task execution;

- *Mental workload*: it measures the cognitive stress that the user perceived during task execution. It can be inferred considering fatigue and distraction signals (e.g. gazing, scratching the head, looking around) and monotony signals (i.e. yawning, gaping, decrease of attention and responsiveness);
- *Information availability*: it considers if the information and data necessary to the user for task execution are easily available when needed;

Interaction assessment is carried out by three assessment metrics:

- *Feedback*: it considers if the environment (product-process-system) offers feedback to the user actions (i.e., visual, acoustic, haptic) to make the user aware about the occurring events;
- *Interaction support*: it measures the ability of the system to drive the user actions according to the right operational sequence, which is usually related to properties such as logical constraints and natural mapping. It is measured by considering the ration between the worker's time for task completion in relation to the experts' time, and considering the number of affordances;

Emotions assessment is carried out by three assessment metrics:

- *Satisfaction*: it indicates the sense of satisfaction and the subjective aesthetic impression perceived during task execution.

2. The experimental set-up

2.1. The protocol analysis for UX

A protocol analysis is formalized to measure the UX through a set of evaluation metrics in order to support requirements definition in product-process design. The protocol is described in Table 1. It details, for each evaluation metrics as presented in the model in the previous paragraph, the adopted measures and the different methods used for collecting data, both traditional (e.g., heuristic evaluation and direct interview) and technological (i.e., digital simulations, eye-tracker, biometrical parameters measurements).

Table 1. The UX analysis protocol

Analysis	Metrics	Measures	Collecting data methods	Assessment rules
Posture	Postural comfort	Joint Angles (deg): - Hip, knee, ankle, back, shoulder, elbow - Head flexion & rotation - Stooping - Max upper arm flexion & elevation Distance from objects (cm) Weight of objects (kg)	- Postural analysis (DHM*) - Heuristic evaluation (1-10) according to SAE scale - Interview (1-5) - Biosensors** - Energy expenditure	*General:* NIOSH 91 UNI EN 1005 Dreyfuss / OWAS Garg equations RULA *Specific:* ISO 4254 ISO/TR 3778 SAE J1814 (cabin) SAE J817 (service)
	Seat comfort	Seat dimensions (cm) Seat shape (surface) Vibration (Hz) Pressure maps (N/mm^2)	- Seat dimensions - Pressure sensors	*General:* ISO 3411 ISO 23205 Dreyfuss *Specific:* ISO 4253 SAE J899 SAE J1163

Analysis	Metrics	Measures	Collecting data methods	Assessment rules
Occlusion	Visibility	View cones (deg.)	- View cone (DHM) - Reach zone (DHM) - Heuristic evaluation (1-10) - Interview (1-5) - Eye-tracking - Biosensors*	*General:* 79/1073/EEC UNI EN 547 ISO 4252 ISO 4254 *Specific:* ISO 5721 SAE J817 (service)
	Accessibility	Distance between the user and reached zones (cm) Steps dimensions (cm) Door dimensions (cm)		
Mental load	Easy of use	Requests of support (no.) Errors (no.) Movements' sequence (no.)	- Eye-tracking - Heuristic evaluation (1-10) - Interview (1-5) - Biosensors* [1]e.g., gazing, scratching the head, looking around [2] e.g. yawning, gaping, decrease of attention and responsiveness	*General:* UNI EN ISO 9241 UNI EN ISO 10075 UNI EN 894 ISO 3767 ISO7000
	Mental workload	Fatigue / distraction signals[1](no.) Monotony signals[2]((no.)		
	Information availability	Time spent to complete the task in relation to expert users (s)		
Interaction	Feedback	Time for task completion in relation to expert users (s)	- Eye-tracking - Heuristic evaluation (1-10) - Interview (1-5) - Biosensors* - Pressure sensors	*General:* UNI EN 894 *Specific:* SAE J817 (service) Bio-measures correlation
	Interaction support	Errors frequency (no.) Affordances (no.)		
Emotions	Satisfaction	Subjective impression (no.)	- Interview (1-5) - Biosensors*	*General:* UNI EN ISO 10075 *Specific:* SAE J817 (service) Bio-measures correlation

* DHM = Digital Human Modelling tools

** The considered parameters are: hearth rate, respiratory rate, real posture data, activity rate, and temperature

Indeed, new technology to monitor the UX has been introduced to bring the gap created by traditional techniques and/or to combine the results obtained by difference sources in order to have more robust results. The last column contains the assessment rule adopted in the study. Even though the reference model is general and could be applied to different context of application, the protocol has been more specifically defined for the automotive sector. It can be adapted to agricultural vehicles, race vehicle, construction vehicles, special vehicles, or urban cars, according to the specific rules considered as reference standards.

2.2. The experimental set-up

The protocol can be put into practice thanks to a proper technological set-up that include the simulation and analysis tools identified in the experimental protocol. For the present study, the following tools has been adopted:
- Siemens Tecnomatix Jack for digital modelling of the environment and simulation via digital human models;
- VICON motion tracking system, made up of 8 infrared cameras and ad-hoc rigid bodies made up by rapid prototyping;
- Tobii Glasses 2 as eye-tracking device;
- Aditech Bioharness 3 as biosensor;

- Xsensor X3 wireless mattress system as pressure sensor.

2.3. The industrial case studies

The protocol has been applied to a set of industrial case studies in the automotive sector, in particular in the agricultural vehicles. In more details, the industrial cases focused on analysing the UX to support tractors' integrated product-process design on three different areas: product design of the cabin, product design of the technical spaces for maintenance inspections), and the design of the manufacturing line, in particular assembly phases. As a consequence, three types of workers as "users" are monitored: vehicle drivers at work, assembly workers in the manufacturing line, and service operators. Examples of UX analysis on the industrial cases are presented in Figure 2.

Experimental sessions were carried out on real environments, where users were monitored by the above-mentioned technologies and video recorded. On the basis of available 3D CAD models, motion capture tracking and video recording, the tasks were simulated also in digital environment to carry out further assessment on digital mock-ups. Data from real and virtual simulations can be properly combined and correlated.

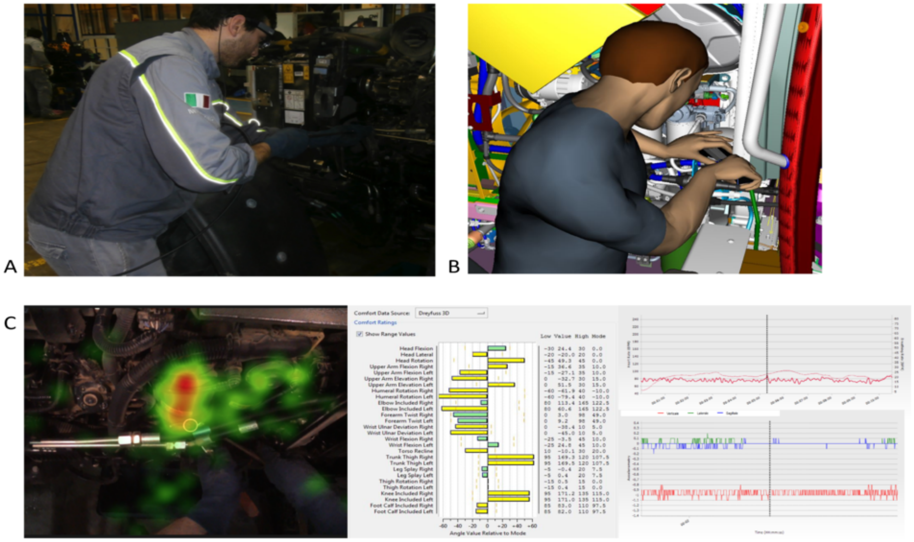

Figure 2. Case study about service operator: real user observation (A), digitalisation (B), and correlation with user monitoring parameters from eye-tracking and biometric data (C)

3. Conclusions

The paper presents a reference model for UX analysis for the automotive sector, consisting of a protocol analysis and an experimental set up. The set-up merges traditional monitoring techniques with digital modelling tools and biometric measuring devices (i.e., eye-tracker, biometrical parameters monitoring, pressure maps). The model has been applied to a set of industrial case studies on agricultural vehicles, focusing on vehicle driving, serviceability, and assembly tasks in the assembly line. It demonstrates the model applicability in industrial context and its validity to include human assessment into the design process. Future works will be focused on the correlation of the collecting data to provide structured guidelines for integrated product-process design.

Acknowledgement

The authors wish to thank you CNH Industrial for the precious collaboration and the case studies, and the Emilia Romagna region for funding the regional project entitled “CREAM: human-CentREd Agricoltural Machinery product and process design”.

References

[1] BCG Group, 2015, *Report on Man and Machine in Industry 4.0: How Will Technology Transform the Industrial Workforce Through 2025?* Accessed: 20.03.2017. Available online at: http://www.bcg.com.cn/en/files/publications/reports_pdf/BCG_Man_and_Machine_in_Industry_4_0_Sep_2015_ENG.pdf

[2] BCG Group, 2015, *Report on Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries*. Accessed: 15.03.2017. Available online at: http://www.zvw.de/media.media.72e472fb-1698-4a15-8858-344351c8902f.original.pdf

[3] M. Hermann, T. Pentek and B. Otto, *Design Principles for Industrie 4.0 Scenarios: a literature review*, Accessed: 15.01.2017. Available online at http://www.snom.mb.tu-dortmund.de/cms/de/forschung/Arbeitsberichte/Design-Principles-for-Industrie-4_0-Scenarios.pdf

[4] D. Romero, O. Noran, J. Stahre, P. Bernus and Å. Fast-Berglund, Towards a Human-Centred Reference Architecture for Next Generation Balanced Automation Systems: Human-Automation Symbiosis. *Innovative Production Management towards Sustainable Growth*, IFIP, Part II, AICT 460, Springer, pp. 556-566, 2015.

[5] C.H. Chen, L.P. Khoo, N.F. Chen, Consumer Goods, in: J. Stjepandić et al. (eds.) *Concurrent Engineering in the 21st Century*, Springer International Publishing Switzerland, 2015, pp. 701-733.

[6] M.S. Sanders and E.J. McCormick, *Human Factors in Engineering and Design*, 7th ed. McGraw-Hill, New York, 1993.

[7] D. Battini, M. Faccio, A. Persona and F. Sgarbossa, New methodological framework to improve productivity and ergonomics in assembly system design. *International Journal of Industrial Ergonomics*, Vol. 41, 2011, pp. 30-42.

[8] E.H. Grosse, C.H. Glock, M.Y. Jaber and W.P. Neumann, Incorporating human factors in order picking planning models: Framework and research opportunities, *International Journal of Production Research*, Vol. 53 (3), 2015, pp. 695-717.

[9] E. Schneider and X. Irastorza, *Osh in Figures: Work-related Musculoskeletal Disorders in the EU – Facts and Figures*, 2010, Luxembourg: European Agency for Safety and Health at Work. Accessed: 28.02.2017. Available online at: https://osha.europa.eu/it/tools-and-publications/publications/reports/TERO09009ENC

[10] M. Hassenzahl and N. Tractinsky, User experience - a research agenda, *Behaviour and Information Technology*, Vol. 25 (2), 2006, pp. 91-97.

[11] N.A. Stanton, A. Hedge, K. Brookhuis, E. Salas and H.W. Hendrick, *Handbook of Human Factors and Ergonomics Methods*, CRC Press, Boca Raton, Florida, 2005.

[12] N.N., *ISO 10075: Ergonomic principles related to mental workload*, International Organization for Standardization, 2004.

[13] M. Koslowsky, *Modelling the stress-strain relationship in work setting*, Routledge, London, 1998.

[14] T. Cox, A. Griffiths and E. Rial-Gonzales, *Research on work-related stress*, 2000, Luxemburg, European Agency for Safety and Health at work. Accessed: 15.03.2017. Available online at: https://osha.europa.eu/en/tools-and-publications/publications/reports/203

[15] P. Hekkert, Design aesthetics: principles of pleasure in design, *Psychology Science*, Vol. 48, 2006, pp. 157-172.

[16] M. Peruzzini, S. Carassai, M. Pellicciari and A.O. Andrisano, Human-centred design of ergonomic workstations in interactive digital mock-ups, in *Advances on Mechanics, Design Engineering and Manufacturing*, 2016, pp.1187-1195.

[17] D. Chang, and C-H. Chen, Understanding the influence of customers on product innovation, *International Journal of Agile Systems and Management*, Vol. 7, 2014, Nos. 3/4, pp.348–364.