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ORIGINAL ARTICLE

Introduction to the special section humans and industry 4.0

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Abstract
Since the start of industrialization, machine capabilities have increased in such a way that human control of processes has evolved from simple (with mechanization) to cognitive (with computerization), and even emotional (with semi/full automation). The processes have also evolved from simple to complicated, and now complex systems, in the emerging context of Industry 4.0. The objective of the special issue "Human and Industry 4.0" is to benefit from studies and results from current manufacturing projects to highlight clues and good practices to design intelligent manufacturing systems for Industry 4.0, then paying attention to human involvements in order to unsure what it looks like in practice and how to realize these systems, especially when it comes to maintenance and operations. This paper aims to summarize the scientific papers that contributed to the Special Issue "Human and Industry 4.0".

Keywords Industry 4.0 · Human factor · Co-operational aspects

1 Introduction

Since the start of industrialization, machine capabilities have increased in such a way that human control of processes has evolved from simple (with mechanization) to complex (with computerization and automation) systems (Boy 2020). The related processes have also evolved from simple to more complex systems. In addition to the traditional rational approach to human–machine integration, this development might also change our emotional relationship to machines (Castelfranchi 2003), and make it necessary to design, engineer and assess this.

Industry 4.0, in addition to a high physical complexity of systems, especially the increasing of the amount of software and networks, also leads to an increasing complexity of these cyber–physical systems (Lee et al. 2015), which leads to a higher mental complexity for the humans involved (Pacaux-Lemoine et al. 2017). This requires tight integration and coordination between software, hardware and "human-ware" into meaningful social cyber-physical systems (Flemisch et al. 2019).

Machines and processes might become so autonomous that humans might lose awareness and control. Besides all autonomy, human intervention may be still required, e.g., to update the manufacturing plan, to modify the process configuration when a machine breaks down, or to assist process-intelligent entities when they fall in a deadlock.

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In view of the challenges of Industry 4.0, the human factor is more and more considered as a key element in addition to hardware and software that should be addressed to ensure overall system safety and efficiency. Moreover, the human factor is also more and more considered for the social aspects, e.g., for the integration of humans on different decisional levels (Fantini et al. 2020; Romero et al. 2017). To reach safe, secure, robust, efficient, and well-accepted industrial socio-technical systems, all decisional levels should be considered to support sufficient cooperation between humans and systems, as well as between humans (Pacaux-Lemoine and Flemisch 2019).

Co-operational aspects have already been studied in other domains than manufacturing, especially in aeronautics, automotive and railway systems, and robotics for example (Flemisch et al. 2019). In these domains, the paradigm of human–machine cooperation strives to balance the increase of machine capabilities for technical tasks with the abilities to communicate with humans and to understand humans, i.e., to cooperate not only with other machines but also with the human. The objective of this special section is to extract the general results of these domains and bring them together with current manufacturing projects to highlight clues and good practices to design intelligent manufacturing systems for Industry 4.0.

Special attention had been given to human involvements, to the connection of theory and practical applications, including engineering, operations, maintenance and training of Industry 4.0 systems. Seven articles were selected for this special section. These papers address the topic with different approaches that can be synthesized according to the type of paper (theoretical/conceptual or experimental), the domain of application, the systems that were developed and evaluated, the studied decisional activities, the methods applied for the design and evaluation, as well as the human factors considered to support human–cyber–physical system integration (Pacaux-Lemoine and Flemisch 2021).

Moreover, the high number and diversity of submissions we received in response to our call is an indication of the growing importance of the cooperation between humans and systems in Industry 4.0. It is also a recognition that this special section fills a gap by bringing important human aspects that could affect Industry 4.0 practitioners and researchers.

2 Types of approach

Such research topics can be tackled with different approaches, from conceptual and theoretical approaches to empiric and experimental approaches. Each approach is fruitful and provide clues to support the design of Industry 4.0 systems able to cooperatively support human activity.

Humans and Industry 4.0 has been addressed with a conceptual approach with a wider point of view to identify several human factors to be integrated during system design as in the paper by (Li et al.), or with a special focus on one point as for ethical attention to be paid to system design (Trentesaux and Karnouskos). In this last paper, the authors present two ethical paradigms to study two types of objectives, i.e., how to ethically design a system and how to design ethical systems. The two ethical paradigms are the deontology when one decides according to immutable ethical rules, and consequentialism when one evaluates according to possible ethical consequences of candidate decisions. The authors, particularly describe the design of ethical systems, integrating an ethical controller based on the mix of different aspects relevant to ethics. Adhiatma develops a concept of incentive gamification for the workers for the organizations in the digital era. The objective is to study the effectivity of gamification on increase in learning experience and performance from an employee's perspective. The concept of incentive gamification is still rarely studied in the context of employee incentives in the human resource management literature, hence, the authors proposed to develop it. Moerman assesses the proto-theorems of graceful extensibility in the railway field by means of adopting pattern matching analysis. Moreover, guidelines for adopting graceful extensibility in complex systems are proposed for further operationalization of this theory in the field. We should note that standards in railway safety mainly focus on technical challenges, while this study shows that the human factor is even more important to ensure safe and reliable railway transport.

Other articles tackle the topic through methodology and experimental approaches. Cognitive Work Analysis was the method used to identify future human and system entities functions, as well as their organization in the case of the study of a production process based on self-organized products and mobile robots by Pacaux-Lemoine et al. Instead of using an existing method, Bounouar et al. propose a new method adapted to the design and the evaluation of the collaboration between a human and a cobot. In the contribution of Tausch, the problem of task allocation in designing human–robot interaction is considered. Instead of using optimization methods, widely adopted in such problems, to obtain the optimal solution for task distribution to humans and robots according to some criteria, the author proposes an experimental approach which places humans at the center of decisions in the task allocation process between humans and robots.

3 Type of applications

Several types of application have been addressed with processes ranging from simple to complicated and complex, often based on system of systems. Manufacturing, transport as well as e-commerce underlines the specificity of the domain, but also the way their results may be extended to other domains.

Four manufacturing systems have been studied. The first one presented an autonomous, ethical controller that might manage fire emergency situation in an autonomous industrial plant (Trentesaux and Karnouskos). The objective of the controller is to handle two simultaneous fires started in a plant by advising workers to go the fastest exit given the simulation results based on fire propagation models. The second and third manufacturing systems deal with human–machine(s) interaction(s) at the operational level of the activity for the second manufacturing system, and at the operational and tactical levels of the activity for the third manufacturing system. For the second manufacturing system, the studies concern the interaction between one human and one cobot to prevent humans from musculoskeletal disorders and handling hazardous products (Bounouar et al.). For the third manufacturing system, the objective of the research is to analyze the ability to support human in the control of a complex and complicated autonomous process based on self-organized production system composed of several production robots linked by conveyors for shuttles selves-motion, and supplied with autonomous/remoted control ground mobile robots (Pacaux-Lemoine et al.). The fourth application (Tausch 2020) concerns a fictional production plant for sweets. The participants were told to imagine being a worker at this plant, and responsible for the production of lollipops. The author also defined the production process as consisting of eight distinct steps that needed to be followed. The participants were randomly assigned to one of three experimental conditions (organization-allocation condition, robot-allocation condition, and worker-allocation condition) in an online questionnaire. The objective was to study the influence of decision workers on the perception of a task allocation process in HRI.

Two transportation systems in the railway domain have been tackled. Trentesaux and Karnouskos, address two kinds of situation with different controls. They deal with a fire emergency situation in an autonomous train and the way an autonomous, ethical controller might manage such a situation. The controller selects a decision according to its integrated rules, with potential assistance from an associated digital twin to simulate solutions. The decision defines when and where the train must stop to save as many passengers as possible. In the paper of Moerman, the application concerns the V250 train and several units: operator, infrastructure manager, suppliers, etc. with many accountabilities and responsibilities, but all with the same final objective, safe and reliable passenger railway transport. The case study was analyzed using a pattern matching analysis that was performed on an organizational level.

The last paper by Adhiatma investigates, as a case study, a service in online selling from four e- commerce, innovative industries in Indonesian which focus on women's products, such as fashion, skin care and baby product. The computed measures were: personal dexterity, incentive gamification, learning experience, and employee performance.

4 Type of systems

The systems investigated in this special issue differ according to the functions they support from information analysis to decision-making and action, according to the authority they have to control these functions, their self-learning ability and the way they interact with human.

In the paper by Trentesaux and Karnouskos, an autonomous ethical controller that aims to find and apply appropriate ethical decisions has been developed. Three strategies would have been defined and followed by the controller according to the classification of the event/state situation. The situation is classified as normal, or classified, but with ethical concerns, or not classified. The controller is an offline self-learning system based on the historization of the decisions and can be done under the control of the designer. Collaborative robots have been studied through their functions they have to complete in the contribution of Bounouar et al. The paper by Pacaux-Lemoine et al., investigates designs of several types of system. At the operational level, ground mobile robots have been designed to move autonomously to reach the geographic point provided by the human operator with whom it has to cooperate. At the tactical level, a decision support system helps the same human operator in the update of tasks planning, to organize production as well as ground mobile robots' tasks. Tausch reports on work on human–robot systems and their interaction considering smaller-scale production settings. Moerman has chosen the V250 train, as this case already shows the complexity involved when people have to deal with such systems and with surprise events. Adhiatma considers organizations in the digital era. The work reported focused on companies that could implement incentive gamification.

5 Type of human and human factors

The future human operators who would be involved in an environment based on Industry 4.0 may be considered from several points of view according to the maturity of the systems that are under development and according to the maturity of the interactions they can have with these systems. Only involved by the way of model based on prescribed tasks, or being any person without any specificity, or professional operator, human involvement and roles are of different consequences on the results and on the implementation of systems.

In the paper of Trentesaux and Karnouskos, humans are passengers of a train and workers of a plant. In these examples, humans are supposed to fully comply with orders provided by the ethical controller. No negotiation is proposed; the system has the authority. The main criterion used is the ethical criterion in line with human safety. In the contribution of Pacaux-Lemoine et al., humans are participants who played the role of the human operator requested to control an intelligent manufacturing system. Several criteria have been used to evaluate the human workload, acceptability and human–machine cooperation, such as a tasks load index, but also dedicated questionnaires based on a cooperative agent model (evaluation of own and other agents' know-how and know-how-to-cooperate). In the paper of Bounouar et al., the criteria related to consider humans are biomechanical and physiological criteria, acceptability and usefulness, usability and ease of learning as well as acceptance, satisfaction and ownership over time. In Tausch (2020), the participants in the online study were chosen using personal networks as well as online platforms, such as Thesius or SurveyCircle. They were assigned to three experimental conditions: organization-allocation condition, robot-allocation condition, and worker-allocation condition. The author used a subjective criterion expressed in terms of satisfaction to study the influence of different decision agents on the perception of a task allocation process in human–robot interaction. Moerman chose humans from a special unit of the V250 train organization: the unit of adaptive behavior (UAB). In these UABs, the author considered: operator, infrastructure manager, suppliers, etc. with different accountabilities and responsibilities. The objective was to compare the theoretical outcome patterns, as proposed by the theory of graceful extensibility, to the empirical outcome patterns from this case. Moreover, guidelines for adopting graceful extensibility in complex systems were identified and validated by key members of the organization, based on the results of the pattern matching analysis. In the study by Adhiatma, the participants were female employees who worked in the marketing department (especially doing service in online selling) from four e-commerce innovative industries in Indonesian which focus on women's products. The studied human factors were: personal dexterity, incentive gamification, learning experience, and employee performance.

6 Type of methods for the design and the evaluation of HMS

In the design of new systems, especially when human operators are involved, method is a central concern. As highlighted by the previous sections, HMS may differ depending on several aspects: type of application with an environment far or close to the real one; type of system that can be simulated or completely implemented; type of human involvement that can be null to completely involved in the design process through several perspectives, both technical and psychophysiological perspectives.

Bounouar et al. present a literature review about several methodologies to extract the main points and to propose a new approach adapted to manufacturing system collaborative robot design and evaluation. The review deals with human-centered design methodologies, such as user-centered design, design thinking, activity-centered design and user-centered design models. A similar approach has been followed by Pacaux-Lemoine et al., but with Cognitive Task Analysis method. However, future users were not known, but imagined, since the studied manufacturing system does not yet exist. The method has been used to identify the future main functions that would be necessary to control such new manufacturing system, especially regarding human needs like workload management and maintenance of situation awareness. Tausch (2020) proposed an online experiment to show that when operators can decide they give more meaning to their activity and their level of satisfaction is higher. The study by Moerman can be considered as a first attempt to empirically evaluate the applicability of the new theory on graceful extensibility. The scope of this study was limited to a single in-depth case study. Adhiatma carried out an empirical study concerning the performance of an employee who works in a marketing department of an e-commerce enterprise. This study showed that there was a significant positive effect of personal dexterity on learning experience and individual performance. Moreover, incentive gamification was proven to moderate the relationship between personal dexterity, learning experience and also employee performance. For the study by Trentesaux and Karnouskos, no experiments with humans were performed and processes and human behavior have been simulated with NetLogo.

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