Identifying the role of human factors in Industry 4.0 Revolution

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ABSTRACT

The current trend and initiative towards a digital revolution in manufacturing is commonly known as "Industry 4.0". Industry 4.0 aggregates various technologies such as data analytics, internet of things, cloud computing. Recently, a new concept and typology of so called "Operator 4.0" were introduced to elucidate human roles and interaction with different technologies that potentially act as enablers in Industry 4.0 revolution. The typology is mainly based on the type of Industry 4.0 enabler technologies i.e. augmented reality, virtual reality, wearable technologies, intelligent personal assistant, collaborative robot, platform for social networks, exoskeleton and big data analytics. This paper, a literature review, aims to provide further contribution on the concept of "Operator 4.0" and identify aspects that need attention and consideration from human factors experts. For each typology, state of the art reviews were collected and used as basis to achieve the aforementioned aim.

KEYWORDS

Industry 4.0, Operator 4.0, human factors

Introduction

In the last decades the computing and internet revolutions have opened up an enormous set of new possibilities that have a profound impact in manufacturing technologies. The term Industry 4.0 refers to the current trend of automation and data exchange in a manufacturing setting. Industry 4.0 fosters the creation of cyber-physical systems, which represents tight interaction and coordination between computational and physical resource, within a smart factory. Cyber-physical systems in a smart factory will be capable of monitoring production lines, create digital twins (or virtual copy) of the production lines and optimise their production lines with little human intervention (Monosotori et al., 2016). The use of cyber-physical systems will bring an improvement in the manufacturing and distribution process by increasing production efficiency and the speed of bringing new products to market resulting in reduction of production costs. They will change the value chain and create a new relationship between human and machine towards human cyber-physical systems which are characterised by the cooperation and co-existence between machines and human in work systems. In such systems, the machines are designed not to replace the skills and abilities of humans, but rather to assist humans in being more efficient and effective. In other words, the design of the work systems will mimic systems that are designed for aircraft pilots, process industry operators and military personnel in which humans will perform supervisory control and involve situation awareness.

Romero et al. (2016) proposed an Operator 4.0 concept and typology which explored a set of key enabling technologies that can support the development of human cyber-physical systems in Industry 4.0. The vision of the Operator 4.0 is to create trysting and interaction-based relationship between humans and machines that capitalises on the intelligence, strength and capabilities to empower human operators. The machines are designed such that they fit with operators' cognitive, and physical needs, improve operators' sensing (physically and cognitively) that allow a dynamic and seamless transition of task/function allocation between humans and machines. They proposed eight categories that were based on how Industry 4.0 technologies can assist operators in human-cyber physical systems. These are:

1) operator and powered exoskeleton,
2) operator and augmented reality (AR),
3) operator and virtual reality (VR),
4) operator and wearable tracker,
5) operator and social networks,
6) operator and collaborative robot,
7) operator and big data analytics, and
8) operator and intelligent personal assistant.

In each typology, they envisaged how each technology could aid operators to become smarter operators by enhancing their physical, sensing and cognitive abilities. Unfortunately, they did not identify and discuss specific challenges of Operator 4.0 typology. This paper aims to provide further contribution on the concept of "Operator 4.0" by identifying and discussing challenges that need attention and consideration from human factors experts. For each typology, existing state of the art reviews were used as the basis to achieve the aforementioned aim.

Results

1. Operator and powered exoskeleton

About half of the research related to power exoskeleton is aimed to support its use for medical purposes (Rupal et al., 2017). Non-medical exoskeletons, which are designed for industrial environments, are generally intended for different users such as soldiers, workers in industrial environments and the elderly. The typical functions of the non-medical exoskeleton range from strength augmentation for physically demanding tasks to reduction of spine and lower back loads while performing bending and lifting. Despite the extensive research in exoskeleton, the use of exoskeleton is very much limited in research environment and is still uncommon in commercial medical and non-medical settings (Islam et al., 2017). In addition, the majority of work is focused on the design and technological aspects (Hill et al., 2017). In fact, the inclusion of user experience as one of several outcome measures to determine feasibility and safety of exoskeleton is rare. Unfortunately, the lack of users' experience or usability studies may result in low user acceptance and technology adoption. While there have been a few studies that identified exoskeleton features from users' perspectives (e.g. Benson et al., 2016), there were few, if any, indications that the findings of these studies were used to guide design and development of exoskeleton. Interestingly, it was reported that users' perceptions and experience of exoskeleton technology might be incongruent (Benson et al., 2016) which means that how users might determine the cost benefit of exoskeleton use will have an important weight on users' acceptance and adoption of exoskeleton.

2. Operator and augmented reality

An augmented reality (AR) system is the augmentation of the real world with digitally generated sensory inputs such as pictures or sounds (Azuma et al., 2002). One of the major advantages of using AR is that it allows users to interact with real objects in addition to virtual contents in the augmented scene, and can amplify human perception and cognition of the real world. AR application has been explored in different contexts such as repair and inspection operations, maintenance, product design, product assemblies, and diagnostic operation. Albeit still in infancy, they have also been applied in various industrial sectors such as aircraft, automotive, railway and manufacturing. AR system generally involves a set of technologies element such as an element to capture images, a display device to visualise the virtual information on the images acquired by the capture element and an element to activate or trigger the display of virtual information. Despite the progress that has been made, AR still suffers from deficiencies related to the aforementioned three technological elements.

While there are various types of display devices associated with AR, Head Mounted Display (HMD) offers a promising option for AR due to their mobility and the capability of over-laying the virtual content in front of the eyes. However, the use of HMD is also associated with visualisation issues such as resolution, field of view, brightness and contrast, stereo vision and occlusion between real and virtual objects (Livingston, 2005). HMD also imposes limited peripheral visibility that could affect the safety of the operations and increases risks of virtual sickness due to its virtual contents low-quality and distortion. AR application is most beneficial when correct decisions on which cognitive tasks should be supported by AR has been made (Palmarini et al., 2018). People using AR applications are shown to be more prone to blindly following instructions which results in less flexibility and resilience in unexpected events and decision making circumstances (Baber, 2015). Thus, critical tasks that require complex decision making and flexibility in handling unexpected events should be identified and excluded from AR applications. Task analysis methods, such GOMS (Goals, Operators, Methods and Selection) could be applied to assist this process.

3. Operator and virtual reality

Virtual reality (VR) systems are a human-computer environment in which users are immersed in and can perceive, act and interact with objects in a 3D world (Bowman and Hix, 2002). As a result of rapid improvement on VR technologies and affordability, it has become common in manufacturing companies. The context of use for VR application more or less overlaps with AR application e.g. training operators' skills, product design, and production simulation. Hardware for VR typically contains two elements. The first element is an output device which provides sensorial feedback (visual, haptic, multi-sensory) to users. The second element is an input device that enables users to interact with the 3D world. More details of existing output and input devices for VR hardware can be found in Anthes et al. (2016).

Despite VR rapid development, cyber sickness is still a persistent issue (LaViola, 2000). In designing the VE, factors that have been shown to induce cyber sickness symptom, for instance long exposure (Kennedy et al., 2000) and unclear and distorted view of 3D scene (Chance et al., 1998, should be avoided. Another persistent issue is distance and depth perception, especially for short distances (Lawson et al., 2016). An emerging issue of VR is the assessment of VR system effectiveness with respect to its initial purpose. It is reported that only a very limited set of evaluation criteria are used for testing the effectiveness of VR systems (Borsci et al., 2015). This issue is crucial, especially in the use of VR as part of a training system. Commonly overlooked evaluation criteria are cyber sickness, acceptance and trust of technology, presence and ease of use.

4. Operator and wearable tracker

Wearable tracker is a device that can measure and collect real time and tailored physical activity, health-related measures (e.g. heart rate, calories burnt) and GPS location. Wearable tracker has the potential to be applied in various domains, ranging from entertainment and well-being, to safety critical systems. It is a relatively recent technology that has been used to encourage healthier behaviour. Some of the wearable trackers also provide motivation support and social support through social media. Over the last decade, a number of commercially available wearable trackers have appeared on the market and require limited training to operate.

A relevant human factors issue related to wearable trackers is user acceptance and long term adoption. The reliability and validity of existing wearable trackers are shown to vary considerably by task, measure and used devices (Soutiere et al., 2016). Studies have shown that inaccuracy due to poor reliability and validity may result in low trust of wearable trackers and lead to low user acceptance (Choe et al., 2014; Meyer et al., 2015). This issue is made worse by the fact that wearable trackers are also shown to be susceptible to both user privacy and network vulnerabilities (Soutiere et al., 2016). One of the identified key barriers to continued use of wearable trackers is wear ability which is defined as the interaction between the shape of the wearable device and the user's body (Dunne & Smyth, 2007). Poor wear ability can result in discomfort, poor durability and easily lost trackers. Human factors input related to wear ability, such as those proposed by Motti and Caine (2014), is needed to improve user acceptance and long term adoption of wearable trackers.

5. Operator and enterprise social networks

Enterprise social networks refer to the use of mobile and social collaborative methods to connect for a broad range of business purposes, activities and processes. In Industry 4.0, enterprise social networks are envisaged to provide connection among the workforce and between the workforce and social Internet of Industrial things (Wuest et al., 2012). Currently, enterprise social networking is used to provide quick and effective connection among the workforce and support knowledge sharing within an organisation. Enterprise social networks that are effectively managed have the potential to offer opportunities to offer the following: i) information dissemination and sharing, ii) means of communication, iii) supporting collaboration and innovation, iv) training and learning, v) knowledge management, vi) management activities and problem solving (Turban et al., 2011).

Unfortunately, although organisational adoption of enterprise social networks is high, adoption of such system by employees (i.e. meaningful and regular engagement) has been reported to be low and (Berkman, 2012). To realise the potential of enterprise social networks, understanding factors and requirements that increase employee motivation to engage with such systems are needed. Other approaches such as phased introduction, for instance starting with a targeted trial group, can also be used and has been shown to lead to successful implementation (Miller, 2007).

6. Operator and collaborative robot

Collaborative robot is defined as robots that are capable to work alongside and in direct cooperation with human operators without compromising the safety of human operators. Effective human-robot collaborative systems require human and robots to have a common goal and work cooperatively through perception, recognition and intention inference. Research in collaborative robot is still in its infancy, with collision avoidance cited as the most prominent technical challenge (Vasic and Billard, 2013). Collision avoidance can likely be reduced by eliciting and defining mutual mental models between human operator and robot (Green et al., 2008).

Varying levels of autonomy that capitalise on the strengths of both the human and robot is of importance in effective human-robot collaborative systems. The system should take advantage of the problem solving skills of a human and the speed and dexterity of a robot. Both task analysis and allocation of tasks between humans and automation can be adopted to deliver human-robot collaborative systems. However, Fitts concept on the allocations of tasks between humans and automation may need to be re-visited and updated to reflect the advancement of robotic technologies. Another aspect is how anthropomorphism, such as humanoid form and personality, may affect user acceptance and trust of human-robot collaborative interaction.

7. Operator and big data analytics

Big data refers to a massive amount of data sets that are characterised by large, highly varied and complex structures as well as difficulties to store, analyse and visualise for further processes or results. On the other hand, big data analytics is defined as the process of revealing big data hidden patterns and secret correlation. It can be used by an organisation to obtain rich and deep insights and gain advantage over the competition.

A relevant human factors issue related to big data analytics is big data visualisation tools. Data visualisation enables users to interactively explore and analyse data so that they can identify interesting patterns, correlations and causation intuitively (Ward et al., 2015). The large amount of data makes it difficult to achieve this manually. This means that big data analytics should provide a mechanism to assist the user whilst simultaneously considering the diversity of users' preference and behaviour as well context of use and tasks. Existing visualisation recommendations (e.g. Vartak et al., 2016; Mutlu et al, 2016; Gotz and Wen, 2009) which take into account factors such as data characteristics, users preference and behaviour as well as context of use and tasks, should be taken into account as part of data visualisation and expanded as the application of big data analytics becomes more ubiquitous. Another aspect that warrants attention from human factors experts is communicating uncertainty (Seipp et al., 2016) and trust towards big data analytics (Barton and Court, 2010). Communicating the sources of uncertainty of big data analytics to users (e.g. from the algorithm model, data quality) are necessary and this information should ideally be delivered as an inherent part visualisation. Likewise, the sources of uncertainty that stem from users to big data analytics systems (e.g. from differences in domain knowledge, experiences in visualizations, previous experience with a similar system) should also be communicated to big data analytics systems.

8. Operator and intelligent personal assistant

An intelligent personal assistant (IPA) is a software system that helps users to achieve their goals efficiently, and proactive assistance based on the current context of the user and environment (Myers et al., 2007). The user model is an essential component of IPA. A model of a user's behaviour, interests, goals and their environment are needed to provide personalised and relevant assistance. IPA has developed rapidly as a result of development in internet and network computing and the demand from users on computers that "understand" them and avoid information and communication overload. IPA can be used for different purposes such as daily life and family, work support and e-learning.

There are several issues related to IPA that require human factors expertise. The first one is identifying the right amount of "anthropomorphism". A higher degree of anthropomorphism raises the expectations of more human-like behaviour and response (Cowan et al., 2017). However, a high degree of anthropomorphism may result in unrealistic expectations of IPA capabilities and lead to dissatisfaction and reduced trust when they are not met (Luger and Sellen, 2016). To a certain extent, IPA is an autonomous agent that detects and acts within their environment. A balance between self-operating (autonomy) and self-evolving (machine learning) in IPA is crucial. The right balance is needed so that perceived user control is maintained, as lack of perceived control may affect a user intention to use IPA.

Conclusion

Despite the trend towards digitised manufacturing, the human operator role is still crucial and will be even more complex and demanding cognitively. It is evident that contribution from human factors is sorely needed across a set of key enabling technologies that can support the development of human cyber-physical systems in Industry 4.0 to ensure an effective symbiosis between human operators and cyber physical systems. In this paper, the identification of aspects that need attention and consideration from human factors experts are based on the existing state of the art of each key enabling technology. The following were identified as needing contribution from human factors experts: 1) supporting inclusion of user experience into design and evaluation of power exoskeletons, 2) identifying correct cognitive tasks that should be supported by AR, 3) assessing VR system effectiveness with respect to its initial purpose, 4) studying user acceptance, long term adoption and wear ability of wearable trackers, 5) understanding factors and requirements that increase employee motivation to engage with enterprise social networks, 6) revisiting Fitts' principles on function allocation to reflect current state of collaborative robots, 7) improving visualisation and communicating uncertainties of big data analytics, 8) identifying the balance between intelligent personal assistant's self-operating and self-evolving. As this study is based on current state of the art review publications, it is likely that areas or aspects that require human factors expertise will also evolve as a result of the advancement of technology.

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