Proposed System for a Socio-Technical Design Framework for Improved User Collaborations with Automation Technologies

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Abstract. To improve human performance, interactive technologies are going towards more automated systems that involve computers, robots and cyber-physical systems into the decision-making process. While automation can lead to increased performance and reduced impact of human errors, interactive technologies without optimal design can have a negative impact on the experience of operators and end-users, leading to suboptimal performance of the automated systems. In this research, we aim to evaluate and refineHuman Work Interaction Design (HWID) framework to be applicable in various highly-automated settings including Industry 4.0 environments. This will be performed via a thorough literature review as the first step. The list of identified factors playing a potential role in various interactive systems will then be evaluated and optimised in three case studies. We will try to understand how to maximise collaborations between the users and the machine in interactive systems. A practical approach for evaluating both employees' and end-users' perspectives in three scenarios with different levels of automation will be assessed. We will evaluate the outputs in multiple levels of organisations, employees and end-users. The ultimate output of the study will be a framework or model that will help in designing future research studies for various automation scenarios, especially semi-autonomous systems that involve high levels of interaction between users and the machine. We will provide guidelines for implementation of the proposed framework in different scenarios. We expect that the framework output of this research will provide a comprehensive guideline applicable to many Industry 4.0 technologies.

Keywords:sociotechnical, human work interaction design, automation, augmentation, Industry 4.0.

1 Introduction

During the life cycle of any organisation, a variety of environmental stimuli will influence its operations and decision-making processes. These external factors are dependent on economic and social factors, political and legislative changes, and developments in technology and human knowledge. The internal environment may also influence various processes and elements of an organisation such as the staff, information and monitoring systems or management policies [1]. Complex organisational systems inevitably rely now on large-scale software-intensive systems. In this paper, we hint at a possible sociotechnical HCI framework with customized value propositions and a case presentation for a future investigation of three different scenarios with different levels of automation.

Socio-Technical System Design (STSD) developments have identified and addressed several problems in understanding and developing complex systems. Despite many positive outcomes, these methods have not materially changed industrial software engineering practices. One of the main reasons behind this is involving users only in the testing stage of any new system development instead of the design process [2].

Currently, 'automation' is one of the main means for supporting operators using systems that feature high complexity. Automation allows designers to transfer the burden from operators to machine by re-allocating the system tasks that were previously performed by human [3].Researchers have studied different aspects of implementation of advanced interactive technologies employing automation in different platforms [1, 3-7].

Organisations can now improve operations and decision making by implementing cyber-physical systems (CPS) and internet of things (IoT), and potentially linking them to blockchain technology in the future. Rising integration of Internet of Everything (IoE) into the industrial value chain is the foundation of "Industry 4.0" technologies [8]. These technologies can improve the end-users' experience via increasing the self-service options, optimising operations and security processes, and enhancing ground asset management and connectivity.

An important point to consider is that implementing new technologies in a complex service-driven work environment (e.g. an airport terminal) does not necessarily and automatically guarantee a positive response from workers and customers [9]. Hence, developments towards future 'smart workplaces' need to be carefully designed in order to achieve expected service quality goals for both end-users and employees. The main purpose of this study is to identify all humanistic/social and technological elements in the design of newly automated systems applicable to Industry 4.0 that are affecting the human and machine collaborations. This paper is organised as follows. Section 2 introduces the findings of the literature review on different factors affecting the human and machine collaborations and categorising them into three main categories. Section 3 proposes the future research outcome by investigating into these factors from three case studies; university library, research platform and an airport.

2 Review

Automating a process that is embedded into people's everyday lives will surely impact their experience. Automation replaces or rearranges people's practices and habits that may have been developed over long periods. Therefore, using automation in interactive systems requires consideration of potential changes on human activity and the new coordination demands on the human operators. These experiences highly depend on the type and level of automation [7] and to what extent the developer has allowed the machine to make decisions.

2.1 Technological elements of interactive systems

Around 1970s and after a series of technological advances labelled as the third industrial revolution (also called "the digital revolution"), the transition towards the fourth industrial revolution (Industry 4.0) is now undergoing that will transform the design, manufacturing, and operation of various products and systems [7]. The increasing integration of the Internet of Everything (IoE) into the industrial value chain has built the foundation for this revolution [8]. The increased connectivity and interaction among systems, humans and machines support the integration of various automated or semi-automated systems, and hence, increasing flexibility and productivity [10]. These automated systems will lead to interconnected manufacturing systems and supply chains with their own challenges.

To achieve sufficient autonomous awareness in a system, efficient integration of smart sensors and mobile devices is required alongside industrial communication protocols and standards. Economic impact of this industrial revolution is supposed to be huge [10], as it promises substantial increase in operational effectiveness as well as the development of new business models, services, products and organisational structures and culture [10-12].

Three key components of Industry 4.0 are Internet of Things (IoT), Cyber-Physical Systems (CPS), and smart workplaces. The main objects commonly used in the Industry 4.0 are RFID (radio-frequency identifiers), sensors, actuators, and mobile phones that interacts with each other and cooperate with their neighbouring smart components to reach the common goal. For all these smart objects and people who are going to collaborate with them, there is a need for setting technical standards to enable them to work.

Industry 4.0 advancements [7] are categorised into 4 main principles in general:

1. Technical assistance,
2. Interconnections,
3. Decentralised decisions, and
4. Information transparency.

The main focus of this research will be on the "Collaborations" sub-principle of the "Interconnections" principle (which includes Collaborations, Standards and Security).

Three type of collaborations are considered in the context of Industry 4.0: human-human, human-machine and machine-machine collaborations. As a result of recent advances in smart interactive systems, employees' experience and access to technology have increased substantially. Recent development of using smart technologies in new domains such as health, education, finance and the impact of Industry 4.0 technologies in manufacturing and logistics have raised new challenges for Human Computer Interaction (HCI) researchers and practitioners.

2.2 Human Work Interaction Design

Human Work Interaction Design (HWID) is a comprehensive framework that aims to establish relationships between extensive empirical work-domain studies and HCI designs. It builds on the foundation of Cognitive Work Analysis (CWA) [5]. HWID is currently positioned as a modern lightweight version of CWA.

HWID studies how to understand, conceptualise, and design for the complex and emergent contexts in which information and communication technologies (ICT) and work are entangled [1]. HWID models are based on the characteristics of humans and work domain contents and the interactions during their tasks and decision making activities (Figure 1). HWID focuses on the integration of work analysis (i.e., CWA methods) and interaction design methods (e.g. goal-oriented design and HCI usability) for smart workplaces. The ultimate goal of HWID is to empower users by designing smarter workplaces in various work domains.

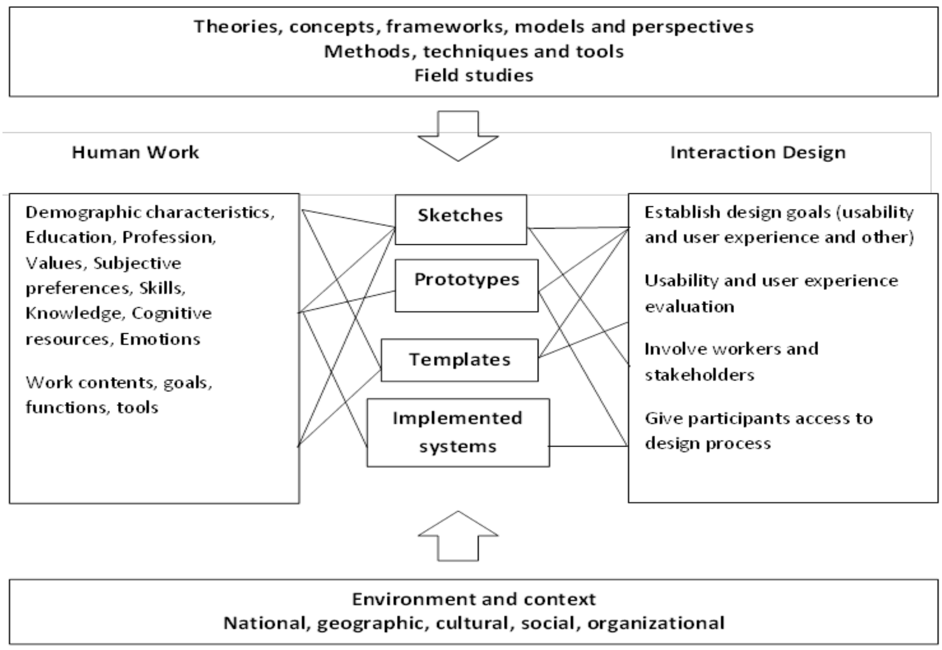

Figure 1. The HWID framework [5]

For applying HWID models to specific workplaces we need to consider several independent and entangled factors[5]. Considering numerous theories, concepts, techniques and methods developed for other work environments is the first step. Environmental contexts such as national, cultural, geographic, social and organisational factors will have an important role in designing optimal HWID models, as they impact interaction between users (i.e. both operators and employees) and smart systems in their work and life. There are more work-related factors including the users' knowledge/skills, application domain, work contents and goals, as well as the nature of tasks or newly introduced technologies to be considered in the interaction performance. Developing HWID models requires establishing design goals, evaluation of usability and user experience, engagement of all stakeholders, and provision of transparent design processes.

2.3 Smart Workplace

"Smart Workplace" is a vision where the organisation is fully connected with all stakeholders via proactive adaptation to the real-time needs of the organisation including operational necessities and customer requests. As an example, security concerns in airports necessitate more investigations prior to the boarding, which results in long queues and waiting times for passengers. Hence, airports need to be more innovative in operations and handling of stakeholders (passengers and workers) and their needs in real time.

2.4 Humanistic elements of interactive systems

To address human element in designing complex interactive systems, design fiction and design ethnography should be linked[13]. This is in line with considering the impact of anthropology on the design's future-orientedness by understanding the cultural meanings and sensitivity to values and context[14]. Analysis of the allocation of functions is necessary to identify the optimal distribution of both functions and tasks between a partly-autonomous system and the user[3].

Physical support of human workers by robots or machines is an important aspect of new technologies. This is due to involvement of users in conducting a range of tasks that are unpleasant, too exhausting or unsafe [15,16]. For an effective, successful, and safe support of users in physical tasks, it is necessary that robots or machines interact smoothly and intuitively with their human counterparts [15], and that humans are properly trained for this kind of human-machine collaboration[8].

The value of information. In collaborations between human and machine, the value of information is now more recognised given high power of the machine in decision-making in highly-automated systems. For instance, informing users about the sensor's reading power of Tesla's automated car can significantly increase their trust [6].

However, other studies show that the number of information items or tasks users receive in an automated process should be personalised and up to the point of their desire/tolerability. Not enough functions allocated to a user will lead to underload and boredom and thus decreased performance. [17] Too many allocated functions will lead to cognitive, perceptive or motoric overload and increase negative emotions (e.g. stress, anxiety) [18] and user's error. [17, 3] Meanwhile, users can cope with emotions after spending some time with the autonomous technology and developing some routines.

Providing an abundance of information and transparency is an important hypothesis in interactive technologies. Trust, transparency and acceptance of losing control (i.e. shared authority between the user and system [8]) can improve the interaction of the user by revealing the ambiguous feelings toward the automation. Other psychological factors under study include worries about practical challenges and security of the technology (e.g. hacking a system) and reliability of the process itself (e.g. flat mobile phone battery for systems that rely on applications). Users may lose their trust in decision-making of an automated system when other humans who will not follow the same process are involved and can impact on the outcome (e.g. if fishermen not using a specific application access to more fish than those using that application).

An important situation is when responsibilities are shared between users and the system. Ability to identify responsible party related to a bad outcome (i.e. user error versus system failure) can impact the performance of users [9]. Controllable designed interface and environment of work, as well as feeling safe while using new technologies, are among other factors that can increase the performance of the users.

Involving users in the design process. The design process should determine the content and format of information to be shared with users in order to create an experience of certainty and trust. Feedback from the users plays a major role for designing such systems. However, the amount and format of the feedback must be well chosen, otherwise it might question the main advantage of automation itself.

Research needs to bridge the gap between the micro-perspective of technology specifications and the macro-perspective of how life will and should change through implementation of that technology. Enacting future systems "in the wild", as a particular form of prototyping, is certainly an important element of this bridge.

Motivating the users to engage with the new technologies is still a challenge due to lack of understanding of the end-users' individual experience and interaction with such technologies. Users can have different roles or backgrounds that can affect their discovery, collaboration and learning of the interactive system[11].Researchers have tried to recruit users for testing their interaction via use of flyers or instructions explaining the technology (a process known as augmentation) [19].

Furthermore, engaging users in designing the automated or augmented product will change their interaction time. The development teams need to familiarise themselves with space and environment of practices, build trust with the employees and improve design ideas. Studies suggest the relations between modes of discovery, design improvements, interaction and socio-spatial aspects. These relations can be developed more as an analytical and design tool to redefine the borders of opportunities for social interaction in daily automated spaces.

2.5 Summary of the review

We believe that there are unmet needs for evaluation and identification of both technical and humanistic factors involved in partly-autonomous systems[7, 3]. Unlike the extensive technical literature on automation, there is a small research base examining the human capabilities involved in work with automated systems[7].

Several factors such as sociological and psychological exchanges, ergonomic, cultural relativity, technology availability and acceptance, etc.,have been proposed to be involved in human-machine collaboration in various settings, especially in higher levels of automation. However, the main problem is that there is no comprehensive list of these factors, and no previous study has tried to develop a model based on these factors. Such a model will be helpful to system designers for developing any new interactive highly-automated system.

We therefore see HWID framework as a funnel for socio-technical design, automation technologies, and information system (*Figure 2*).

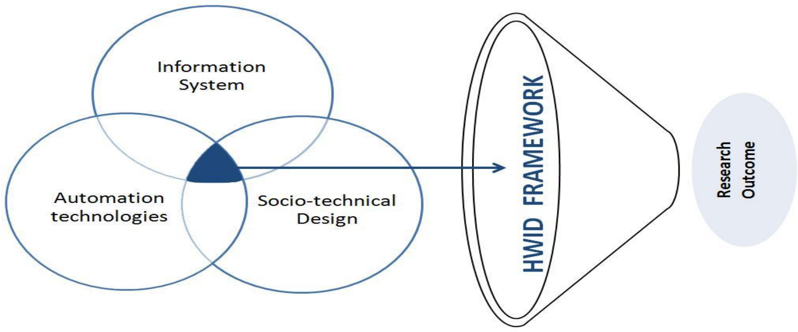

Figure 2. Main scopes of proposed HWID research on user collaboration with automation in complex settings

3 Proposed further research

For investigating independent and entangled factors related to human and machine collaborations in automated systems, we propose a practical approach for evaluating both end-users' and employees' (or operators') perspectives in an automatous environment.

First step (current stage) in this research is to produce a list of relevant factors from different sources including: review of the relevant literature, contact and interview with experts in this domain, and observation of some smart workplaces. This comprehensive list will then be evaluated and optimised in two scenarios (scenario 1, University of West London Library, and scenario 2, Indian Research Platform). These scenarios were selected carefully based on potentially important factors including socio-behavioural (e.g., work pattern), psychological (e.g., trust in system), demographical (e.g., wealth and ethnicity), and geographical characteristics of their user populations.

We will analyse previously available (via literature review and expert opinions) and newly-gathered data (via questionnaires and interviews) to produce a model to be validated onscenario 3 settings (i.e.,London based airport). By several iterations in this highly automated environment we will refine and provide the final output of the study, which will be a tool/guideline for designing HWID models for various interactive technologies. Figure 3 below depicts the proposed process of research in this study.

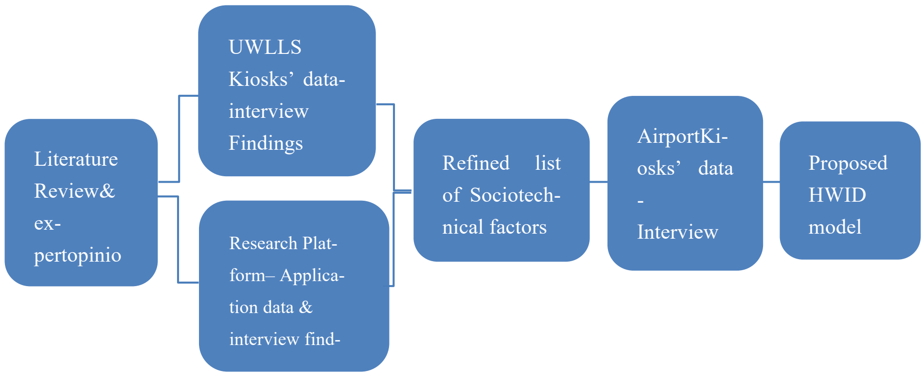

Figure 3. Research procedure

Given the variety of environments and different levels of automation, we will potentially achieve different lists of factors that affect the performance of both operators and systems. This will help us to update the list for different environments. In the final scenario, current shortcomings and future opportunities will be evaluated by using an HWID model for future smart workplaces using Industry 4.0 framework.

Conclusion

In summary, the overall objective of this paper was to present a review of the possible theoretical background for a to-be-developed sociotechnical HCI framework, including customized value propositions for the work domain of choice, and, finally, to present three scenarios to be considered in future research. One of the outcomes that the current stage is a comprehensive list category in main principle and number of sub-principles of the factors impact the machine and human counterpart collaboration from sociotechnical perspective. This is what we hoped to illustrate with this paper as start of a series of papers in different scenarios with various automation level.

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