Collaborative Decision-Making for Human-Technology Interaction - A Case Study Using an Automated Water Bottling Plant

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Abstract. The Fourth Industrial Revolution places different rapidly advancing technologies at the centre of developing autonomous systems. Previous and current research focus on the developing and testing state-of-the-art technologies related to an autonomous environment. However, most industrial environments in the South Africa, and many other developing countries, are still making use of mixed environments. In mixed environments, automated systems and humans need to collaborate for the completion of a process. Currently, there exists very little research on how a collaborative decision-making process can be developed such that the worker’s acceptance and adaptation to the process is taken into cognizance. This research identifies the lack of collaborative decision-making processes as a research gap. This paper focuses on the research done in this field with an extensive literature review, followed by a review of potential models for human technology interaction. The paper then uses the case study of an automated water bottling plant to advance the study in collaborative decision making. The paper concludes by discussing the advantages of collaborative decision.

1. Introduction

The Fourth Industrial Revolution places different rapidly advancing technologies like the Internet of Things (IoT), Internet of Services (IoS), Internet of Everything (IoE) and Cyber Physical Systems (CPS) at the centre of developing autonomous manufacturing systems [1]. The development of these systems within the environment of Industry 4.0 expects significant changes in tasks and demands on the human in the manufacturing process and recognizes that humans and machines are homogeneous parts of a larger diverse body consisting of collaborative and autonomous components [2].

According to the Industry 4.0 concepts, all objects in the manufacturing world have assimilated processing and communication capabilities which highly affect machine-to-machine communication. However, a considerable consequence is that of the effect it will have on human-to-machine interaction [3]. It is very occasional that automated systems are solely autonomous; a level of human interaction is almost always present although this challenge is not always considered [4].
This research identifies the absence of collaborative decision-making processes as a research gap, as the successful operation of an automated system is highly dependent on human-technology interaction (HTI) as well as efficient collaboration between the workforce and the automated system. This research utilizes the case study of an automated water bottling plant to see how potential models for Human Technology Interaction can be incorporated to an automated system to enable Collaborative Decision Making.

The paper is structured such that, first a literature review is done to showcase the advances in the field of collaborative decision making and human technology interaction. Secondly, an analysis is done on some of the best practices used around the world when it comes to human-technology interaction. Thirdly, the paper details the case study used in this research. The paper is rounded off with discussions on the benefits of using a collaborative decision-making approach for human technology interface.

2 Literature Review

Industry 4.0 is concerned with the communication, analysis and use of information to notify and enhance all the processes associated with the manufacturing sector and connecting manufacturing processes from design up to the end of the product lifecycle [5]. As stated in the introduction, the success of automated systems is highly dependent on the interaction between humans and machines as well as collaborative decision making in the process. As Industry 4.0 evolves, so does the way we interact with technology and this leads to more sophisticated interfaces for communicating and interacting with technology [1].

With the development of computers and different technologies over the past few decades, a paradigm shift was brought on to human-computer interaction (HCI). Sensors allow for new ways of interacting with technology[6]. With the introduction of mobile devices, the way we interacted with technology has changed significantly - the use of touch and gesture-based interaction has become the norm.[7].

However, the recent advances in computing, machine learning and sensor technology will have a much wider impact on how we interact with machines. Three terms that are used in the field of computer science to refer to the interaction between humans and machines are human-computer interaction, human-machine interaction and human-technology interaction. It is noteworthy to discuss these three terms related to the interaction with technology due to the nature of the rapid development in the Industry 4.0 era and the impact it has on collaboration between humans and machines.

2.1 Human-Computer Interaction (HCI)

Since the 1960’s, the rapid advances of information systems and accompanying technologies led to the extensive development of research on human-computer interaction [8]. Human-computer interaction (HCI) is a multidisciplinary area of study that focusses on the design of computer technology and the interaction between humans and computers which includes cognitive science, computer science and human-factors engineering [9].

HCI refers to the study of the ways in which technology influences human work and activities [10]. Another definition is, that “HCI is the process of communication between users and computers (or interactive technologies in general)” [11]. The term “interactive”, in the context of interaction design, refers to the creation of interactive technologies that support people in executing everyday tasks [12]. Interaction with these technologies takes place through a human-computer interface which can be defined as the communication between a human and a computer system by using input and output devices to enable a user to use a computer system in an efficient, effective and satisfactory manner [13] [14].

Previous research has indicated that computer manufacturers and software designers have identified the benefits of creating usable products and argue that creating usable interfaces may have a huge impact on the interaction, usability and effective use of applications and devices [15]. Product design should consequently be supported by the user experience to allow for the adaptation and acceptance of
technology by the workforce in the Industry 4.0 era. The user experience (UX) refers to the expectation of users of having systems or applications to not only function well, but to be fun, satisfactory, efficient and enjoyable to use [7].

2.2 Human-Machine Interaction (HMI)

Since the beginning of the development and design of interactive technologies almost every thinkable work environment; from office work, health care, computer design, engineering, etc. were involved in the advancement of technology [8]. However, according to Hoc [8], in these work situations the user mainly controlled the computer and the work was mainly passive in comparison to the current Industry 4.0 era where more complex, connected systems are developed through automation. According to Bachman et al. [14] the term human-computer interaction can be replaced by the term human-machine interaction (HMI) as human-machine interfaces vary widely, from the control panel of a vehicle manufacturing plant, the touchscreen of a mobile device to a robot on the factory floor that a user interacts with.

Human-machine interaction (HMI) refers to the communication and interaction between a human and a machine by means of a user interface [16], [17]. In autonomous environments robots and machines are becoming more complex with tasks and activities becoming less structured and, as a result interaction with humans to complete these tasks, become less and less [4]. The growing complexity of autonomous systems and robots has led to the study of how humans interact with robots and how to design systems capable of achieving tasks where the human still plays a pivotal role in the completion of tasks [4], [18]. Input and output components are needed for interaction between humans and machines.

Humans needs a way of instructing the machine what to do via an input device such as a mouse, keyboard, touch screen, switch, etc. while on the other hand the machine should be able to update the human of progress and execution of commands by means of some output even if it is a status light or an alert that can be heard [18]. The designing of such interfaces is a challenge in the sense that the interface should be functional, logical, effective and satisfactory to use.

Experts specializing in the design and development of human-machine interfaces have done a lot of research in the designing of usable interfaces [19]. What works for an engineer does not necessarily work for the human that needs to interact with the machine. This promulgates the importance of Human Technology Interaction.

2.3 Human-Technology Interaction (HTI)

Taking a human-centered approach to the advancement of technology, it becomes evident that the development of technology takes place in a social setting and is formed by the operational objectives and processes of usage [20]. Hancock and Chignell [21] argues that human factors is not an isolated design issue but a point of view to technological innovation and development that has an enormous influence on the economic success of technology.

Human-technology interaction (HTI) is an interdisciplinary research area that focuses on the development of products for human-environment interaction [14]. HTI refers to the interaction between humans and technology through hardware and software with any technology, such as computers, robots, machines, smart monitors and virtual and augmented reality. Although augmented and virtual reality is already used in manufacturing, the technological advancements will allow companies to make more comprehensive use of this technology to provide workers with training, real-time information for improving of decision making, work procedures and collaboration [22].

HTI encompasses the processes, actions and dialogues that a user engages in to interact with technology, whether it is a computer, machine or robot. It also implies the study of interaction between users and computers, deals with people, software applications, computer technology and the ways they influence
each other and as such balance the human interface with information systems and other technologies [19].

In the Industry 4.0 era we encounter a wide variety of HTI – any time a human uses technology, there is some type of hardware and/or software involved that enables and supports interaction. HTI concentrates on the aspects in which technologies facilitate the interaction between the human and the environment [20]. An important goal of HTI is to develop principles and algorithms for autonomous systems to enable safe, direct, effective and trustworthy interaction with humans [4]. Figure 1 depicts the comparison between HCI, HMI and HTI whereby the current new technologies and trends are assisting in more than just human machine interface but have moved towards interaction and interfacing technology between humans and autonomous systems.

**Figure 1. Comparison between HCI, HMI and HTI**

As the demands and allocations of humans and technology are rapidly changing, the study of communication and cooperation between humans and technology becomes extremely important. This is referred to as collaborative decision making.
2.4 Collaborative decision making

With the evolution of Industry 4.0, more and more autonomous devices are moving out of laboratories and into our daily lives to provide humans with services and the support of decision making in different processes [23]. Collaborative decision making is an approach being used to facilitate efficient science-based decision making [24]. In the Industry 4.0 environment, designers, technical practitioners and users should work together to articulate the wants, needs and limitations of the users of autonomous systems to enable the creation of systems that addresses these elements.

Collaborative decision making means to work together with someone on something to reach a common goal [25]. A team is formed when humans and machines work together on a mutual task where a team is defined as a small number of participants with similar skills who are dedicated to a shared goal for which they hold themselves responsible [18]. In a collaborative environment the team members should know the intentions of the other team members and what they are doing. In HTI it will usually be the human who states the goal while the system must assist the human to take on the task and work toward reaching the common goal [18].

This allays a common fear that Industry 4.0 has brought about, which is the fear of job losses. However, advocates of Industry 4.0 give some reassurance that workers will be trained and re-skilled to work alongside automated machinery [26]. In the collaborative decision making environment, Industry 4.0 systems will be able to complement tasks and activities performed by humans and also perform many tasks that go beyond what humans can do [27].

Realistically, some jobs will decrease, while others will grow and many occupations will change as requirements for more and new skills becomes necessary [27]. Re-skilling of workers will become a reality as they will have to adapt to systems that becomes progressively proficient in the workspace [8]. Designers and software engineers should aim for a collaborative design process for the design of interfaces that can be utilized in the controlling, monitoring and collection of data in an autonomous environment.

3. Potential models of HTI

This research uses the case study of an automated water bottling plant for the creation of a division between the set of jobs required by the autonomous system as well as the human related to the factory setting of the water bottling plant. We propose three different potential models for collaborative decision-making in HTI allowing several alternatives. The three categories are: system first, human first and a combination of human and system (hybrid).

3.1 System first

This is the state that the case study is in its present state. In this scenario, the system is in full control of the allocation and execution of tasks, thus the human will have to adapt to the actions of the system. The automated water bottling plant will generate a flexible interactive mode for the improvement of system efficiency and operation safety. In many cases an autonomous system’s actions are characteristically defined and can be displayed using similar one directional communication channels [7].

Planned system actions can be conveyed to humans via portable devices e.g. virtual or augmented reality glasses. This will allow the human to pay attention to the activities that the autonomous system is executing and pay attention to any possible errors or safety issues that may happen. The human will not be interfering with the activities performed by the autonomous system, unless intervention is required.

3.2 Human first
Currently the water bottling plant is fully automated with sensors detecting variables such as water tank levels, bottle size, bottle filling, etc. The speed at which the system communicates and responds with instructions from the current interface is much higher than what a human can react to or execute. To determine an optimal model it is necessary to investigate what the impact will be of using only human input to test the optimization of production of the water bottling plant. When this model is utilized, there will be almost no communication between the system and the human which will prevent the disadvantage of the lack of speed of human execution in relation to robot execution.

The system will not be able to predict how the human will behave or what instructions the human will give and as a result will need to wait for instructions from the human before execution of tasks take place. In this model, all the decisions will exclusively be taken by the human. However, this lack of information exchange may inevitably lead to the system being inefficient. An exchange of information between the autonomous system and the likely actions of the human, may prevent the system from becoming inefficient.

3.3 Combination of human and system (Hybrid)

The third option is to implement a hybrid system where the human and autonomous system have equal responsibility with communication channels for planned actions in both directions – from the human to the system and from the system to the human. This approach can be described as collaborative decision-making as discussed in section 2.4. Humans need information on the intentions of the autonomous system and in turn the autonomous system need information about the humans in the relevant environment for decisions to be made collaboratively. A hybrid approach may just assist humans and machines, systems and robots to work together, but there are still many research questions that need answering before such a conclusion can be reached.

4. Water Bottling plant case study

As alluded to previously, the paper utilizes the case study of an automated water bottling plant to conduct research on Human Technology Interaction for collaborative decision-making. The water bottling plant was a concept that was put forward by the management of the Central University of Technology (CUT), Free State to produce their own bottled water for internal use.

An economic feasibility study done in conjunction with the technical study determined that the water bottling plant, hence forward referred to as the plant, needs to produce bottled water in 500ml and 750ml size. A 3-dimensional model of the completed plant [28] is shown in Figure 2. As depicted in Figure 2, the plant has three major units being the source and tank unit (A), the bottle manufacturing and storage unit (B) and the water filling unit (C).
The 3D model depicted in Figure 2 was successfully modelled in Simulink and optimized using MATLAB as part of the technical feasibility. The order for the bottles is made online and stored in a cloud. Based on the date of completion and the status of constraints like amount of water available and number of bottles in the storage, the optimization model executes the order. The optimization model is practically executed using three Smart Manufacturing Units (SMU’s) driven by a combination of sensors and Programmable Logical Controllers (PLC’s). This is depicted in Figure 3.
5. Discussions and Conclusions

This research paper identified the lack of collaborative decision-making in automated systems as a research gap and argues that the successful operation of automated systems may benefit from a human-technology interaction approach with the introduction of collaborative decision-making in the process. The research makes use of a case study for an existing fully automated water bottling plant which currently functions at optimal levels.

The aim of the study is to introduce collaborative decision-making to the automated water bottling plant and investigate whether it will have a positive impact on production when humans and the automated system work together in the decision-making process.

Evidence exists of similar research performed by Klumpp et al. [7] where three methods were focussed on to determine the fundamental role of Human-Computer Interaction in automated environments in production logistics and in the Industry 4.0 environment [7]. The research emphasized HCI in connection with effective cooperation between workers, automated robotics and transportation systems. Testing of the hypothesis was executed by first using only the human in the decision-making process, secondly, only the robot and thirdly a hybrid of the human and the robot. The results yielded from this particular research [7] was that the acceptance level was the highest where humans and robots were equally cooperating during the decision-making processes rather than only robot- or human centred methods [7].

This research will make use of a similar test on the three models identified in Section 3 to determine whether it will have a comparable effect to the research done by Klumpp. The ultimate goal is to suggest the best method for bridging the gap between autonomous systems and the workforce and suppose that collaborative decision-making will make an impact on optimizing the production of the automated water bottling plant. The research will also investigate the role that the interface plays for ensuring that the human knows the exact conditions of the processes being executed and be able to capture the input from the human side accurately.

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