The Human in the Loop in Automated Production Processes: Terminology, Aspects and Current Challenges in HCI Research

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Abstract
With the constant penetration of automation and robotics in industrial contexts, the nature of human tasks and involvement with technology is changing. The increasing intelligence and sophistication of systems enables human operators to not only manually operate them ("in-the-loop"), but also to transition into a supervisory role ("on-the-loop"), where machines are monitored sporadically and over a distance. Various models within and across application areas to categorize the degree of automation and human involvement therein have been proposed.
This paper investigates "the human in the loop", by revisiting previous considerations of this term and by placing it into the context of human automation interaction in the production sector. Examples of current research projects are provided, in order to critically reflect on the relevance of the "Human-in-the-Loop" concept in the innovation of automated production processes.

Keywords
Human in the Loop, Industry 5.0, Human Automation Interaction

1. Introduction

Automated systems, even with the highest levels of automation, require some form of human involvement. Especially with high automation, the form of involvement has often been called "human in the loop" (HITL, or HIL). Given the rapid innovations of intelligent and automated systems, HIL has become a ubiquitous term for virtually all application fields. The common denominator of the term "Human in the loop" is that it refers to the involvement of a human to provide oversight, feedback, or intervention as needed in a process or system. The involvement of a human can be within decision-making or problem-solving, or the validation or correction of an automated system's output.

Recently, the notion of human centricity has been nurtured by the Industry 5.0 initiative of the European Commission [25]. Industry 5.0 complements the existing paradigm of Industry 4.0. by placing the human factor (along with sustainability and resilience to sudden disruptions) back in the center of the manufacturing and development process [1][24]. While automation can eliminate many routine tasks from human operators, it also increases the complexity of decision-making and action in exceptional situations that require human intervention. Therefore, it is essential to foster collaboration between humans and machines, rather than seeking to fully automate process control.

To achieve this collaboration, human operators are understood as highly relevant actors, who should be enabled to engage in the decision-making process of automated systems and contribute their expertise and insights. In fact, the human centricity concept of Industry 5.0 calls for further research on the process of designing and adapting intelligent technologies in work processes with a focus on the human in the loop,

by empowering human operators to improve productivity as well as well-being of workers [19][11].

Given the importance of placing the human in the loop especially in this field of Industry 5.0, it appears relevant to come up with clear definitions of the human in the loop in human machine collaboration, to leverage the strengths of both agents. Figure 1 shows typical scenarios of Industry 5.0 where novel forms of user interactions within the human loop are currently investigated.
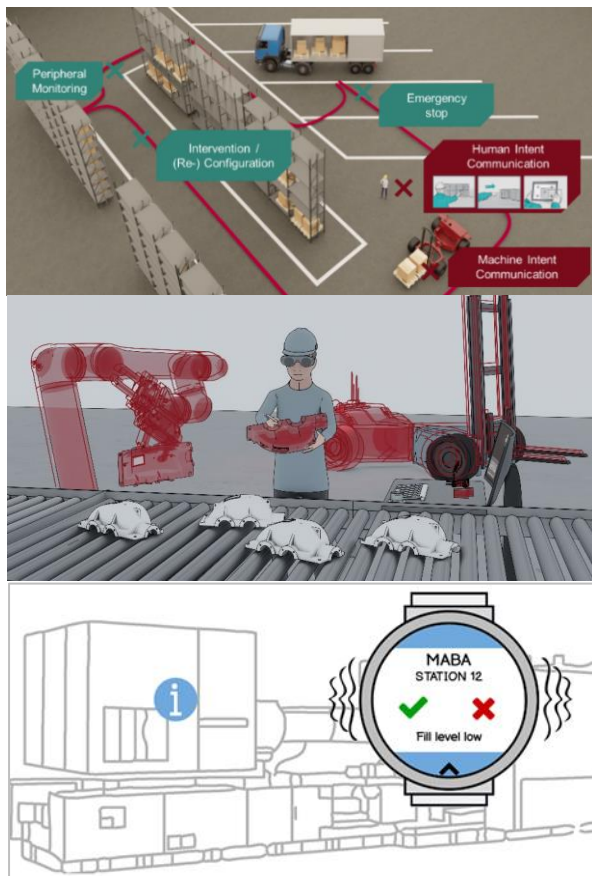

Figure 1: Examples from Industry 5.0 scenarios, where interface design for the Human in the Loop is particularly challenging: Top: Automated material handling vehicles at logistics site; middle: visual inspection of die-cast parts (AIT Lighthouse project "AI-enabled and sustainable automation"); bottom: unobtrusive monitoring of production.

As outlined before, the term has been used in many professional and practical fields, and as a consequence, it has remarkably varying meanings and connotations across domains. Even more notably, HIL has often been dropped as a term, but almost never accompanied by a concise definition or terminological reference. Especially, the field of industry 4.0 and 5.0 has only been roughly considered with regard to human-in-the-loop [22].

In this paper, we make an attempt to come towards a more comprehensive understanding of the human in the loop for Industry 5.0, by reviewing the concept and its uses across research fields. We start out by providing an overview over the "etymology" of the term and its provenience. Then, we elaborate on some of the key aspects of the human in the loop, highlighting especially the multifaceted nature and different requirements and manifestations in the domain of Industry 5.0. We conclude with a critical discussion about the value of the "Human in the Loop" concept for different purposes.

2. The provenience of the Human in the Loop

Human factors engineering: The presumably earliest appearance of the term "human in the loop" has been introduced in human factors and control engineering theory, where control loops are used to describe the flow of decisions and human-machine interactions ([12][13][16].

Simulation: Also in the field of simulation for training and research purposes, the term is central to describe simulations that are not only driven by deterministic computer models, but that also offer the involvement of humans to represent the "unpredictable behaviour" of humans and to evaluate the fit for purpose of systems and models in real-world situations ([2][15][5]).

Data analytics: Human-in-the-loop concepts are also discussed in data analytics, where humans are involved when "data problems" occur. According to Doan [6], HIL is used for fostering software communities, building knowledge graphs or extracting insights from data.

Machine learning: Current references to HIL mostly are related to the Human as an important part to improve machine learning models [23]. In the HCI domain, human-in-the-loop concepts have been used to integrate user-centered design with machine learning [3][21].

Cyber-physical systems: Another stream of research investigating human-in-the-loop concepts relates to Cyber-physical systems, of which Industry 5.0 will be a key application field [20]. Notably, in this area, the presumably most concrete human-in-the-loop definitions involving human machine interaction within production environments have been provided [18][4].

3. Considerations of the Human in the Loop for Industry 5.0

In the following, relevant aspects for appropriating and reflecting the human-in-the loop concept for human-centric design of Industry 5.0 are presented.

3.1. Who is said human?

Depending on which of the above-discussed research fields is concerned, the identity of the human involved in the loop can be either direct users (e.g. in case of CPS usage) or domain experts (in case of machine learning and data analysis).

Especially Industry 5.0 processes can actually involve different types of users at once. In the case of the automated material handling vehicles scenario depicted in Figure 1, the users to be kept in the loop could involve a foreworker, a fleet coordinator, an onsite worker, or a driver of a semi-automated vehicle. In other cases, such as the visual inspection of die casting or the overall monitoring of production processes for quick manual interventions in case of failure, the human to be kept in the loop is mostly the worker in charge of the quality control (cf. [17]).

Models to create taxonomies for characterizing the human (in the loop) may incorporate these roles, along with other relevant accounts, such as Cimini et al. [4], who suggest a categorization of activity types for role definition (data acquisition, state inference, state/system influencing, actuation).

3.2. What makes a loop, actually?

It is not always clear, how metaphorical "the loop" is thought to be. Depending on the research field, a loop can be an implemented and operationalized real-time system control loop [14] a simulated process, a data analysis activity, a machine learning loop, or a process distributed among various cyber-physical system parts and human actors. Of course, the latter is most relevant for Industry 5.0 processes. While first approaches have been provided [4][18], so far a structured analysis of what exactly constitutes a loop and how to support user-centered representations of a loop appears to be missing.

3.3. In, on or out of the loop

For the human factors study on real-time interaction with CPS, it is important to differentiate between different relations of the human in relation to the loop. Merat et al. [14] differentiate between in-the-loop situations, where the operator is in full physical control and monitoring the situation, on-the-loop situations (no physical control, but monitoring the situation), and out-of-the-loop situations (no physical control and no monitoring OR physical control with monitoring).

Out-of-the-loop situations, where an operator is moved out of a control loop due to automated control, can lead to limited awareness of system states [7][10]. While the OOTL phenomenon has been studied in depth in the area of automated driving [14], this is less the case for Industry 5.0 scenarios.

3.4. Within and among loops

Industry 5.0 scenarios are often characterized by distributed teams of workers. This more systemic view has been investigated early on in human factors research. For example, Moray and Hancock [16] described human interaction with manufacturing systems as a hierarchy of nested control loops, where the physical plant is at an inner loop level, operators at an intermediate loop level and management at an outer loop.

Cimini et al. [4] analyze "social human in the loop" systems, by comparing different allocations of human teams and systems (from direct human-human communication to networked communication among humans and machines). Their paper also provides a first glimpse into human-machine interface approaches for such systems, but still remains at the surface.

4. Conclusions

There is an overall consensus that in virtually all situations and setups of future production environments, the human should remain at a central position. In this context of arguing for the significant necessity of human involvement, the term "human in the loop" has been convincingly used, while often in a rather superficial manner. Likewise, the "human in the loop" term as a key system characteristic highlighting human involvement for improving machine learning, data analysis or training outcomes.

As shown above, the human in the loop is a concept that has been used in various application contexts but less often been defined in a concise way. Despite a considerable number of papers carrying the human in the loop in their title, so far

no comprehensive overview about the various uses of the term as such has been provided. This paper provides an attempt to review the term "human in the loop" from such a broad perspective and to gather relevant inspirations and remaining gaps for the application of this concept in the field of HCI in the Industry 5.0 domain.

An overall observation is that, although the human in the loop should be a genuinely human-centered aspect, the term has often been used by engineering domains. When considering the human in the loop as a way to communicate requirements and design human-automation interaction solutions in a project team, one can see the current gap that they mostly remain at a relatively generic level when it comes to the actual user interaction to be described.

We believe that in many Industry 5.0 use cases, an elaboration of the human in the loop concept would be beneficial as a conceptual design tool. This certainly applies for those types of scenarios that involve a rather small number of loops (e.g. quality control interfaces, see Figure 1) and where human interventions come sporadically (e.g. automated vehicle fleet management in logistics settings or human interventions in a highly automated manufacturing process, see Figure 1).

For other, more complex scenarios that can less easily be explained by loops and human placements therein, such as human-robot teaming and joint cognitive systems, the usefulness of a further elaboration of the term may be more questionable. Further research is encouraged to clarify the added benefits of the human-in-the-loop concept for Industry 5.0 and beyond.

Acknowledgments

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