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Workstation–Operator Interaction in 4.0 Era: WOI 4.0

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Abstract: Currently machine operator interface is mainly focused on providing the operator with easy control over the production processes and easy access to related information. However, myriad of recent technological advances in variety of fields including AI, raise the question of what could be added to the operator-machine interaction capabilities and how. This article explores the possibilities to harness new capabilities in cognitive and behavioral knowledge as well as AI and "Industry 4.0" literature in order to outline the architectural framework and capabilities of future work-station–operator interaction as a principal component of the human–machine interaction in the "Industry 4.0" era. The proposed system is named "Workstation–Operator Interaction 4.0" (WOI 4.0). The equipment's capabilities allows an adaptive ongoing interaction that aims to improve operator performance, safety, well-being, and satisfaction, as well as production measures. The paper describes the main elements of the proposed WOI 4.0 architecture, and illustrates a case of smart machine–operator interactions. The contributions, limitations, and implications of the proposed WOI 4.0 system in the "Industry 4.0" arena are discussed, and future research directions are presented.

Keywords: HMI, Industry 4.0, Cognitive Manufacturing, Affect Computing, Context Aware Computing.

1. INTRODUCTION

Myriad of recent technological advances (for examples see Table 1) in variety of fields including AI, raise the question of how to harness these capabilities for improving future production systems. The interaction between an operator and its workstation is a major area where these capabilities could greatly contribute. This paper defines and illustrates a framework for a smart work-station–operator interface in the Industry 4.0 era. We named the proposed system WOI 4.0 (Workstation-Operator Interaction 4.0) since it is expected to play a leading role in cognitive manufacturing (Larovyi, 2015) and eventually evolve to its full future potential.

Industry 4.0, is expected to change many aspects of Human Machine Interface (HMI) incorporating intelligent user interfaces (Gorecky et al. 2014). Lucke et al. (2008) describe future context-aware systems that will operate in the background of the workstation and intervene only when a need arises, to assist people and machines in executing their tasks (ibid., p. 115). Yang et al (2009) states that any computerized workstation in Industry 4.0 era is expected to possess human-like visual and auditory capabilities that could easily identify the operator's levels of fatigue, distraction (Kutila, et al., 2007), attention (Bouchner, , et al., 2009), confidence, stress (Healey & Picard, 2005), and so on.

Table 1. Examples of operator's state detection technologies and associated references

Operator's state	Reference of detection technology
Attentiveness	Omidyeganeh et al. (2011)
Fatigue	Davis et al. (2014), Yang et al. (2009)
Learning	Jesus et al. (2002), Won et al. (2014)
Sadness/happiness	Rani & Garg (2014)
Dexterity	Islam & Bai (2017)
Satisfaction	Chastagnol et al. (2014), Kaiser & Sap (2009)
Distress	Delean (2016)
Heart attack / Cardiac arrest	Sikdar et al. (2016)
Seizure (e.g. epilepsy)	Ramgopal et al. (2014)
Respiratory difficulties	Li et al. (2014)
Unstable/falling down	Flores-Barranco et al. (2015)

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These future abilities will allow the system to track and monitor the operator's psychological and physiological states and get involved in case of need. In line with this vision, this paper suggests a WOI 4.0 framework for a workstation system that collects information regarding the operator's physiological, emotional, and cognitive states; and analyses it. At the same time, the system also tracks the conditions, events, and processes in the workstation and the surrounding local area. Based on these two tracking of processes, the suggested WOI 4.0 system is able to improve objective and subjective production measures.

The rest of the paper is structured as follows: section 2 describes the proposed WOI 4.0 framework; sections 3-5 describe parts of the WOI 4.0 framework and their architecture: section 3 focuses on the "Observation" part of the framework; section 4 describes the "Analysis" part, and section 5 describes the "Reaction" part of the framework. Finally, section 6 concludes the paper.

2. WOI 4.0: THE PROPOSED FRAMEWORK

In this section, we describe the building blocks of the proposed WOI 4.0 framework (defined in the introduction). The proposed framework is comprised of three main elements: (1) Observation, (2) Analysis, and (3) Reaction. The Observation element receives inputs from three sources: the operator, the environment (including the work-station), and the reaction element (reacting to an earlier interaction or event). This structure creates a closed loop that constitutes the core of the interaction—an ongoing monitoring, adapting, and reacting mechanism that iteratively collects, analyses, and produces data. These three elements and their proposed internal architecture are depicted in figure 1.

3. WOI 4.0 OBSERVATION ELEMENT

The Observation element is based on a dynamic process that tracks both the operator and the surrounding environment (mainly the workplace) to infer the ongoing state of affairs and the trends, based on recent changes. As shown in Figure 1. We propose an implementation architecture of two systems: "Operator observation system", and "Workstation observation system". Each of these systems is described next.

3.1 Operator Observation System

The Operator Observation element is composed of three major software agents (a software agent is a program operating in the background with persistence, autonomy, social ability, and reactive/proactive capability). The major software agents of each of the two Observation elements are: (1) inputs agent, (2) momentary profile agent, and (3) profile trajectory agent. In addition, it is suggested that the Observation element would also include a personality database that can be updated periodically. The personality database is a static data depository that characterizes the individual operator's personality. Each agent (of the observation system) will now be described in more detail and schematically depicted in Fig. 1.

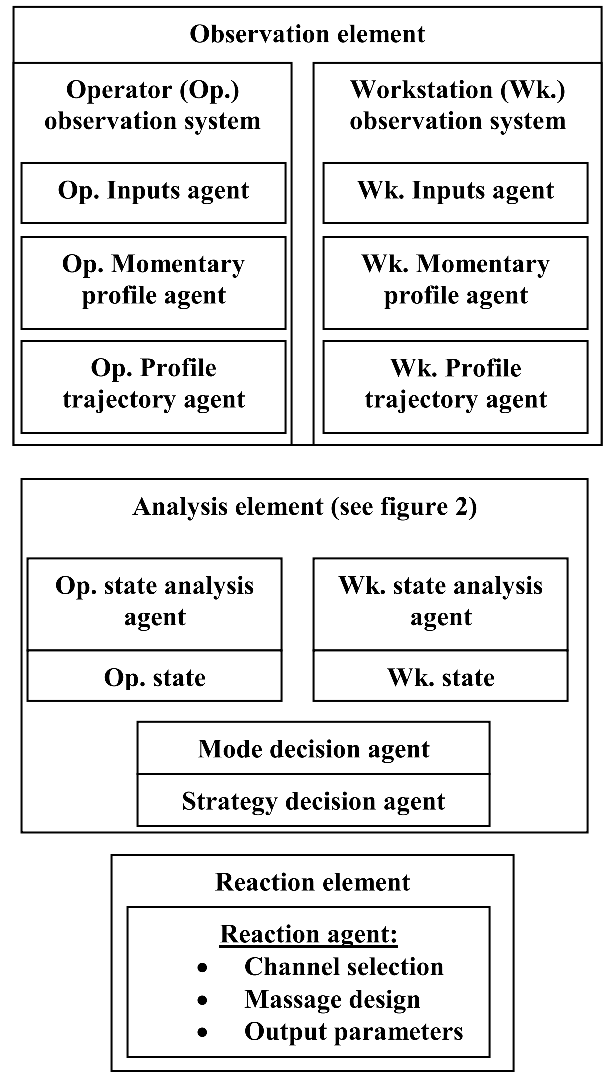

Fig. 1. WOI 4.0 framework and its proposed architecture

3.1.1 Inputs agent:

This agent (see Figure 1) collects external signals from various cameras and sensors and converts them into a crude information vector in various dimensions in very short time-frames. This vector affords an instant view of all visible and measurable aspects of the operator's state. Data are gathered regarding the operator's body language, gestures, body movements, eye movements, facial expressions, verbal and auditory utterance, and physiological measures such as heart rate and perspiration.

3.1.2 Momentary profile agent:

This agent (see Figure 1) periodically collects the inputs vectors and generates a new vector representing the operator's stable granular status as reflected during the previous few seconds by the inputs vectors collected in the previous stage. The momentary profile presents granular and momentary constant or average values of various indicators. Some examples may be:

1) Physiological indicators: heart rate, perspiration level, body temperature, overall stress level;

2) Body positions and movements: right and left hand gestures, body gestures, legs position, trunk position;

3) Eye activity: blinking rate, location of center of view, eye movements rate, pupil size, focus distance, eye contraction;

4) Facial muscles: lips posture, frown, contraction of various facial muscles;

5) Utterance: meaning, volume, tone, emotion, confidence.

3.1.3 Profile trajectory agent:

This agent (see Figure 1) periodically integrates a sequence of momentary profiles and reflects the changing trends in them over a longer time unit. The algorithms operating in this stage attempt to find a pattern or a trend of change. For example, a single indication of fatigue constitutes an entry in the momentary profile, whereas a profile trajectory includes a sequence of indicators for an increasing fatigue level (indicating a high likelihood of an operator falling asleep). Such a profile trajectory agent represents a granular change in the operator's behavior, which is crucial for obtaining data on personal, subjective operator’s measures such as satisfaction, burnout, and, most importantly, errors prevention and identification.

3.2 Workstation Environment Observation system

The workstation environment monitoring system (see Figure 1) monitors the operator’s working conditions, namely, the workstation state. The structure of this system is similar to that of the operator observation system. The inputs agent receives continuous data signals from different sensors with regard to physical conditions such as noise, temperature, light, humidity, background movements, etc., and transforms them into a vector of values that are updated continually and frequently. This information is collected in short time-frames by the momentary profile agent, which reflects the status of the workstation environment during the previous several seconds. The profile trajectory agent collects the workstation momentary profiles over a longer period of time. For example, noise detectors receive input with regard to harmful noise levels in the workstation. If they persist for a few seconds, the momentary profile registers harmful noise. Each momentary profile update is stored in the profile trajectory. Thus, after a few updates indicating no change in the noise, a trajectory profile representing an ongoing harmful noise level is accumulated. This information is integrated with data on other environmental background noise and information on current processes, and is transferred to the analysis system. The latter utilizes this information to assess the situation and recommend suitable action.

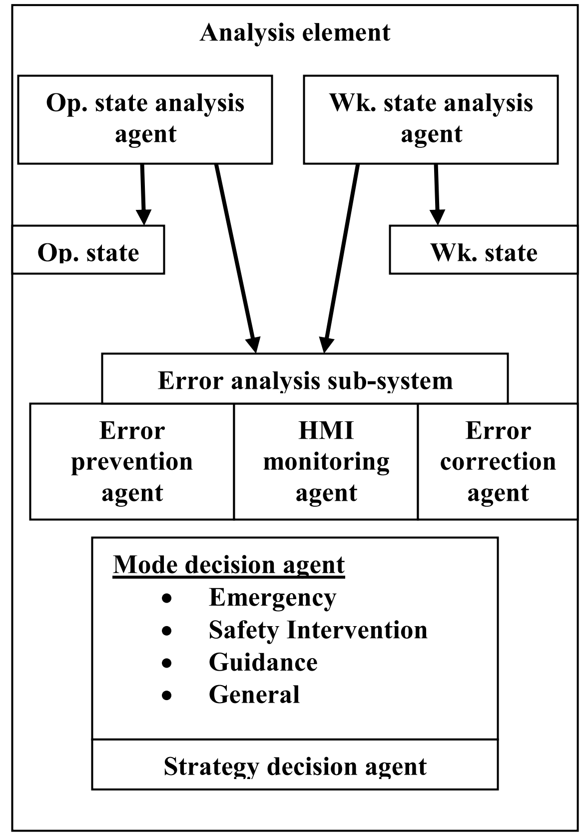

Fig. 2. Proposed detailed architecture of “Analysis” element

4. WOI 4.0 ANALYSIS

Analyzing the information gathered continuously from the operator and the environment is the core function of the proposed system. Information collected in the observation element is processed in order to achieve an overall understanding of what is happening in the workstation, including the operator’s state and the environmental state. In addition to building a diagnosis, the analysis also strives to select the best reaction strategy to the states of a specific operator and workstation environment. This is done by creating several candidate strategies and a prognosis for each strategy for choosing the best alternative.

The system analysis comprises the following elements: trajectory analysis and classification, HMI monitoring, error detection and avoidance, and sub-system planning for determining reaction mode and strategy (see Figure 2).

Operator’s State Analysis agent: Integrates static, momentary, and trends information from the Operator Observation element in order to diagnose the operator’s overall physiological and cognitive steady state (or steady trend). This agent’s main task is to classify the current operator’s state (Figure 2). The latter—examples of which include fatigue level, high fever, distress, sadness, respiratory difficulties, seizure, learning, low dexterity, etc.— are discussed below.

Mental and physiological state: This characterization is generated by the Operator's State Analysis agent (see Figure 2) and represents a general stable granular operator's state as inferred from the Inputs agent, momentary profile agent, profile trajectory agent, and the static personality data. It is worth noting that given the diversity of operators' personalities, similar data from the momentary profile and trajectory may lead to different insights. An important aspect in determining the operator's state is the use of granular measurement and modeling, based on the trajectory and momentary profile relative to the individual user and standard data. Data of this type enable the system to infer not only productivity and objective measures, but also personal subjective measures such as level of satisfaction, happiness, fatigue, attentiveness, or burnout.

Workstation State Analysis agent: This agent is analogous to the Operator State Analysis agent (Figure 2). It integrates static, momentary, and trend information from the workstation observation system in order to diagnose the workstation state or steady trend.

Workstation state: This is the classification of the Workstation State Analysis agent (Figure 2). The workstation state describes the work environment in terms of general measurements such as temperatures, humidity, lighting intensity, noise, etc. as well as the processes occurring in the workstation.

Error Analysis sub-system: In the case of a human error, the following process may take place. First, the system interprets and classifies data collected during the Observation stage as the commission of an error or as a sequence of actions liable to cause an error. The second situation generates a preventive action in the response stage. The Error Analysis sub-system (see Figure 2) deploys three different agents: (1) error prevention and avoidance, (2) development and assessment of reaction strategy effectiveness, and (3) detection of accident occurrence or prevention, or rectification of an error or accident.

Error Prevention agent: Given the importance of preventing errors and the complexity of predicting an upcoming error, a designated agent in the system monitors the state of both the station and the operator in order to identify the likelihood of an accident or an error occurring. The information concerning the probability of various risks is transferred to the planning sub-system. In cases of likely accidents and errors, the agent triggers an appropriate response mode and strategy to prevent damage.

HMI Monitoring agent: This agent monitors the overall interaction between machine reaction and operator's state. It monitors the changes in operator and workstation states in response to the system's reaction. In other words, this element facilitates the evaluation of the result of previous interactions based on the diagnosed states and the system's response. Thus, the effectiveness of the WOI 4.0 reactions is assessed, thereby helping to evaluate the need to change strategy.

Error Correction agent: This agent detects accidents and errors and strives to correct them or guide the operator if assistance is required (Crump & Logan, 2013). It receives information from the Error Prevention agent when an error or accident

Planning sub-system: includes the mode selection agent and the strategy decision agent.

Mode selection agent: This agent selects the most appropriate mode of operation based on both current data regarding operator and workstation states and trends from a repertoire of possible modes. Following are four examples of such modes:

1. Emergency: Work must be halted and the workstation shut down forthwith in order to avoid an immediate and serious accident. The relevant management/personnel must be notified. This mode is triggered by the error detection and avoidance element described above.

2. Safety intervention: The system must react to prevent a potential risk or violation of procedures. The intervention includes warning the operator, and in many cases shutting off parts of the system and activating other parts. This mode is also triggered by the error detection and avoidance element, but is implemented in lower-risk situations.

3. Guidance: This mode comprises assistance to the operator in the form of minor error prevention and explanations of how to proceed with work. The operator can determine the guidance level according to his/her current knowledge and concentration level on a particular day (e.g., choosing among three levels of guidance: Intensive, Medium, Low).

4. General: This is the default mode of operation, i.e., it operates unless it is turned off. The system mainly collects data but refrains from taking action—even if there is some merit in reacting—unless the operator actively requests its intervention.

Additional modes of operation may be developed for specific production needs. Moreover, data collected in the HMI monitoring element may assist in designing granular, customized modes of operation for a specific operator.

Strategy decision agent: This element selects the most appropriate strategy based on the mode of operation and the data obtained on a specific operator. For each mode of operation, there is a range of response strategies that differ in their impact. For example, one response strategy may to entail remaining silent and not intervening. Another strategy may involve eliciting suggestions that the operator may accept or reject. A third strategy is to change environmental conditions such as temperature, humidity, background music, or even lighting. Data on the operator's personality, previous behaviour, and previous interactions with the system are helpful for predicting the strategy that will produce the optimal results.

The preference for one particular strategy is far from trivial. The system should consider various aspects such as what the operator expects from it, which response may irritate him/her, and which response would satisfy him/her. The aim of the strategy is to maximize its influence in both objective operator’s measures such as productivity, quality, efficiency, time standards, etc., and subjective operator’s measures such as satisfaction, general well-being, motivation, burnout level, etc. For example, an operator who reduces his/her speed of work because he/she is thinking about h personal problems may cause objective productivity measures to decrease. A direct response strategy that urges him/her to speed up ignores his/her distress, and consequently lowers his/her level of satisfaction and motivation, can cause an additional decrease in production. Conversely, a response strategy that acknowledges his/her problem and proposes a break or some kind of assistance may be more suitable for the purpose of maintaining productivity and maximizing both objective and subjective measures. This situation highlights the importance of emotional intelligence for WOI 4.0, as if it were a talented human manager who reacts sensitively to the operator’s psychological needs.

5. WOI 4.0 REACTION ELEMENT

This element defines the implementation of the chosen response strategy from the analysis stage. In this stage, the system translates the reaction strategy into a specific reaction that best suits the circumstances according to the knowledge obtained in the analysis stage. The reaction implementation has three dimensions. The first is a perceptual channel, which determines whether to use an audio, a visual, or a tactile message. The second determines the frequency, timing, and length of appearance of the message (Yang & Dorneich, 2015). The third is intensity, which relates to the loudness, brightness, or strength of the message as a function of the perceptual channel applied. For example, if the mode of operation is safety intervention—specifically to warn the operator of a potential procedure violation—the system may use an audio message specifying the nature of the violation and the corrective action required; for instance, the message may be sounded five times at 75 decibels over a period of five minutes.

The machine reaction affects the operator, and the effect is recorded in the operator’s tracking system**.** The machine reaction may fluctuate among these three dimensions according to the operator’s diagnosed momentary profile (see Figure 2, Observation), in an iterative manner. Pursuant to the chosen reaction, the momentary profile and the trajectory profile change continuously in a process that constitutes the core interaction between the system and the operator. This interactive process links the Reaction stage to the Observation stage. The same interactions are performed on the workstation area for detecting relevant processes and conditions.

6. CONCLUSION

This paper describes a proposed framework for a workstation human machine interaction (HMI) in the Industry 4.0 era. The paper describes the overall structure for the proposed Operator Workstation Interaction framework (WOI 4.0), as well as its features and elements. It then discusses the WOI 4.0 architecture, capabilities, and limitations.

The framework is general enough to allow a broad range of production types in a wide variety of work environments. The WOI 4.0’s capabilities enable adaptive, ongoing interactions that enhance the operator’s safety, well-being, performance, and satisfaction. The paper describes the main elements of the proposed WOI 4.0 architecture and discusses the suggested interface with an operator. The paper focuses on the futuristic additional elements of human machine interface assuming that best current practices of human machine interface would become the standard of Industry 4.0 era. The implications of these interactions for factories of the future are yet to be discovered in terms of worker satisfaction, performance, and burnout. Furthermore, the development of artificial emotional intelligence has enormous potential for future research on WOI 4.0. Another example for of a vast research area is the development of artificial social capabilities. This would necessitate developing a system interface for a team of operators or engineering the interaction of a mixed group of systems and people.

Finally, future research may investigate how to improve context aware computing (in particular, remote background identification of events and processes).

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