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Challenges for Interface Designers in Designing Sensor Dashboards in the Context of Industry 4.0

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***Abstract*—**Industry 4.0 is the fourth industrial revolution that focuses on interconnectivity of machine to machine, human to machine and human to human via Internet of Things (IoT). Technologies of industry 4.0 facilitate communication between human and machine through IoT and forms Cyber-Physical Production System (CPPS). In CPPS, multiple shop floors sensor data are connected through IoT and displayed through sensor dashboard to the operator. These sensor dashboards have enormous amount of information to be presented which becomes complex for operators to perform monitoring, controlling and interpretation tasks. Designing handheld sensor dashboards for supervision task will become a challenge for the interface designers. This paper reports emerging technologies of industry 4.0, changing context of increasing information complexity in consecutive industrial revolutions and upcoming design challenges for interface designers in context of Industry 4.0. Authors conclude that information complexity of sensor dashboards design has increased with consecutive industrial revolutions and designs of sensor dashboard causes cognitive load on users. Designing such complex dashboards interfaces in Industry 4.0 context will become main challenges for the interface designers.

***Keywords*—**Industry 4.0, sensor dashboard design, Cyber-physical production system, Interface designer.

I. Introduction

INDUSTRY 4.0 is a fourth industrial revolution which triggers the trend of sensor data exchange using IoT in manufacturing industry [1]. Industry 4.0 includes CPPS [2]. CPPS is advent of technologies such as IoT [1], Wireless Embedded Network Systems (WENS), Virtual Reality (VR), Mixed Realities (MR), Network Cloud Computing (NCC), etc. [3]. CPPS deals with enormous amount of multiple shop floor sensor data, and these sensor data are presented on handheld HCI based sensor dashboard. Interpretation of presented information in sensor dashboard is become more complex for operators [4]. Thus, there will be a huge scope of information visualization for sensor dashboard design in Industry 4.0 context.

In the present manufacturing scenario, supervising sensor data through web-based control system (holonic control system) [5], [6] provide ease in plant operation, but information visualization still becomes a challenge [7]. Due to increase in type of information coming from various sensors of the shop floor, complexity of information has been increased [8]. Manufacturing sequence management and controls applications such as mixed model production lines, the demands on the decision makers to rapidly interpret complex data and formulate a corrective response are challenging. However, a review concluded that there is little published information on the application of visualization to manufacturing sequence management [9].

Interface designer are facing challenge in visualization of large-scale sensor data for designing efficient interfaces for sensor dashboards. Recently, a pilot study on graph visualization reported that for numeric dataset, a 'Bar Graph' has maximum correct response and 'Area Graph' has lowest response time [10]. In order to reduce the information complexity in sensor dashboard designs, designers need to understand the types of information (numeric, graphic, text, image, etc.), amount of information, interaction method and information navigation. There could be many ways in order to present multiple sensor data such as augmenting an electronic screen with a projected display to help visualizing sensor data in a smart manufacturing set up [11]. Researchers are trying to evaluate their designs and propose guidelines for designers, but designer should also need a new method to consider the Industry 4.0 scenario, task complexity, information presentation techniques, etc. for designing complex sensor dashboards.

The aim of this research is to highlight the need to reconsider the sensor dashboard design in context of Industry 4.0 and identifying the challenges for designers to design sensor dashboards for Industry 4.0 factories. The contributions of this research are (a) Industry 4.0 and CPPS role in Industry 4.0 (b) changing context of increased information complexity in consecutive industrial revolution (c) identify the challenges for designers of sensor dashboards.

II. Industry 4.0

The phenomenon of Industry 4.0 was first mentioned in 2011 in Germany as a proposal for the development of a new concept of German economic policy based on technical advancement [3]. The concept has introduced the fourth technological revolution, which is based on the concepts, manufacturing models and cyber technologies that include IoT and internet of services based on perpetual communication via internet that allows a continuous interaction and exchange of information not only between humans but also between human to machine and machine to machines. Physical systems (like, sensors and actuators) of the manufacturing unit are identified and controlled through remote locations with the help of authorised internet protocols [12], [13]. This fusion of internet protocols with physical things is known as IoT [1]. With IoT, monitoring and controlling of process operations are becoming possible from anywhere and anytime. Operators of Industry

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4.0 face challenges in operating complex sensor dashboard designs because dashboards are presenting enormous amount of machine data along with other factory data like maintenance data, operations data, logistics data, supply chain data, production planning data, managerial data, etc. Due to information complexity designer scope for designing sensor dashboard interfaces increases. Eventually, designers' demand for such complex interface increased. Designer should first identify the areas where they can work and improve the design efficiently. The design scopes are mentioned in section V where designer can re-think in order to make more efficient interface design.

III. CPPS in Industry 4.0

CPPS is forecasted backbone of the Industry 4.0 [2]. CPPS is characterized by sharing information such as production operation, planning, management and maintenance etc. over the internet with multiple systems in the smart factory. Technologies like, NCC, WENS, IoT, Internet of Service (IoS), Machine to Machine communication (M2M) etc. are the key technological ingredients of CPPS and industry 4.0 subsequently. CPPS will facilitate operators to identify, manage and control physical machines over the internet [12].

1) *NCC:* It is a computer network which provides network interconnectivity between cloud-based applications. Cloud network is the main element for storing and providing shop floor sensors data in a real time. With the help of cloud-based real time applications, operator can fetch multiple shop floor sensor data at any time and from anywhere. Examples of cloud-based applications are IBM Bluemix, Cayenne, Think speaks, Google app engine, Apple icloud, Amazon EC2, etc.
2) *IoT:* It is the interconnectivity of physical devices like, motors, actuators, sensors, transducers etc. over internet where physical devices are accessed through internet. *IoT* technology is also useful for identification, management and control of physical thing over internet.
3) *WENS:* It is a set of embedded hardware and software which helps in connecting sensors to the cloud network application platform. Also, WENS useful for connecting near field device to wide field devices over wireless network. Examples of WENS hardware are LORA WAN, Zigbee, etc.
4) *M2M:* It is a wireless mode of exchanging sensor data between machines in a real time. Also, it is referred as communication between machines to machine over wireless protocols. Machine to machine wireless communication protocol has a limitation of distance. Due to use of small range communication protocols, machine can communicate with the other machines in a very short distance which ranges approximately from 5 to 10 meters of distance. For machine to machine and human to machine communication protocol like MQTT, LWM2M, etc. have been used in shop floors. These protocols specifically used for targeting low power devices which have to conserve power so that they can operate for a long time. Shop floor sensors are connected with embedded hardware and run on these *M2M* protocols in order to create WENS.

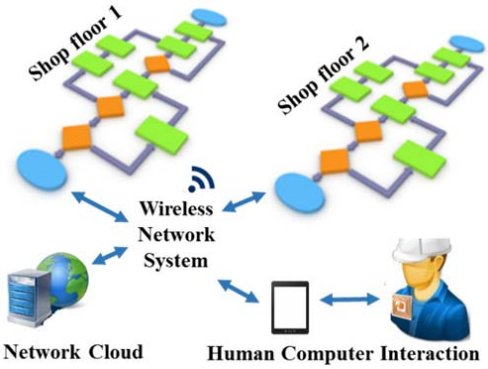

Fig. 1 Elements of CPPS in industry 4.0

CPPS technologies enable touch-based hand-held sensor dashboard for operators to monitor more than one shop floor production information (Fig. 1). Such handheld computing device displays various sensors data, operational data, maintenance data, managerial data, etc. on a dynamic screen with multiple functions [14]. Also, production process information can be sent and received from one factory to another factory using IoT technology.

IV. Changing Context of Information Complexity in Consecutive Industrial Revolution

In Industry 1.0, display dials were attached with the process itself. Operator needs to walk around the factory to take different sensors measurement. Size of the display dials was large, and most of them were analog type [15]. Dials were placed not in a sequenced or grouped, which increases the visual complexity and chances of error in task. Sensor data gathering of the factory by a single operator consumes a lot of time and increased the factory operation tasks. Increased tasks and visual complexity of sensor dashboard designs increased the cognitive load of the operator. Cognitive load on the operator lower downs the production efficiency of the factory. The accuracy and quality of the manufactured products were suffered due to the design of the sensors dashboard in Industry 1.0 scenario.

In Industry 2.0, attached sensors in the processes were collated at one place known as control room, and supervision of whole production process was started through control rooms. In this industrialization, dial size was slightly reduced, and use of different dial designs in control dashboard gets started. Production processes were sectionalized, and sensor dials were placed closely based on their functionality. Visual complexity of sensor dashboard design was increased. More than one operator was appointed for supervision of the production process and sections of the production process was distributed to them (refer to Fig. 2).

In Industry 3.0, use of computers was started. Physical display dials of the control rooms (in Industry 2.0) were converted into graphical user interfaces. Using GUI, sensor

dashboard design was presented in a more meaningful and perceptible format [17]. Operator can monitor and control the whole production process alone. Also, operator communicates to the higher officials if control panel gets errors due to sensor failure in the production process. Sensor dashboard computers are connected with server computer of the factory which can store the sensors data for future reference. Real time factory process can be stored efficiently. The accuracy and quality of the manufactured products have increased compared to Industry 2.0. As design of sensors display dials are similar to user's mental model and presented in a simplified manner thus, complexity of dashboard design is slightly reduced.

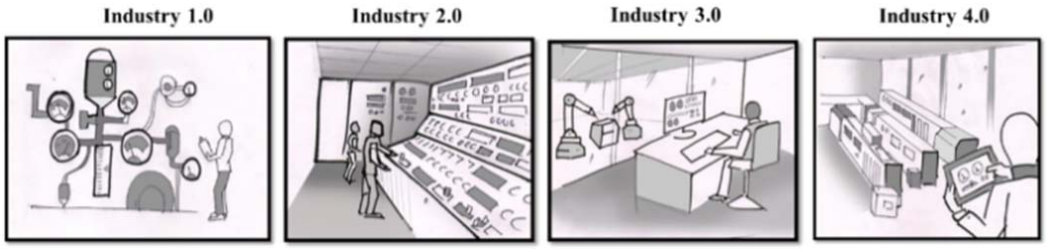

Fig. 2 Changing sensor dashboard design and its context with technology in consecutive industrial revolutions: Industry 1.0 to Industry 4.0 [16]

In Industry 4.0, a handheld HCI based sensor dashboard for factory supervision enables to present enormous amount of data such as sensor data, operation data, production planning data, supply chain data, managerial data, maintenance data, etc. which make interface design more complex. New graphics for presenting relevant technology elements in sensor dashboard will be a challenge to match the operator's mental model. Thus, complexity in design increases due to types of information, amount of information, multimodality interactions, novelty in tasks and scenario of use.

In disruptive industrial revolutions information, complexity of interface design increases and causes cognitive load on users. Further, designing interfaces become challenges for the interface designers.

V. Challenges for Designers for Designing Sensor Dashboard

Challenges for designers include visual complexity, task complexity, and cognitive load, critical scenario of use, multimodality interaction and interoperability. Designer challenges are discussed in the following points:

1) *Visual Complexity:* The presentation of irrelevant information to the user creates complexity in users mind. Task difficulty along with complex info graphics causes mental workload on users and thus performance of the user decreases. It also been reported that large amount of information presented to the user in the same time, leads to error during task fulfillment [18]. According to Gestalt theory of visual perception for user interface design that information presented in complex visual forms, ungroups, high proximity and discontinuous information increases the visual complexity in users [19]. Several researchers have reported that visual complexity in interfaces has been increased with time, and visual complexity becomes one of the core challenges for the designers to design new interfaces relevant to the scenario of use. Higher the visual complexity, higher the reaction time and cognitive load on the users in monitoring and controlling tasks [20]. A study reported that analog display in control panels has less cognitive load compared to digital display control panels [21]. Thus, visual forms, graphics, numeral, text, icons etc effects the user's visual perception and extraneous cognitive load.
   Visual complexity of sensor dashboards will increase when large amount of sensors information presented on sensor dashboards, size of dashboard is small and use of multi-screen displays while operating production process. In order to design new display system for sensor dashboards, creating new visual forms, graphics, icons, etc. will be challenging for designers. Designer should first understand existing user's mental models, tasks and scenario of use before designing visual forms, graphics and icons for presenting sensor information in dashboards.
2) *Task complexity:* Increase in the number of steps, type of information, frequency of task etc in sensor dashboards will increase the task complexity. Task complexities in interface design increases the chances of task errors and lead to reduce in operator performance. Therefore, designers should consider task complexity while designing interfaces for sensor dashboard in context of industry 4.0. Task analysis can be done to know more about the steps involve in a task and their implication. Hierarchy Task Analysis (HTA) is a well-established task characterization technique used in design process.
3) *Cognitive load:* According to Sweller's cognitive load theory- the more information that is delivered at once, the more likely that the users will not actually learn what is being taught nor they will be able to recall upon that information for later use. The information presented to the user should not be overloaded but grouped in a way that it does not increase the cognitive load of the user. Thus, designers should consider cognitive load theory for designing interfaces for sensor dashboards.
4) *Critical scenario of use:* Scenario for operators would become complex due to cyber flexibility in industry 4.0 environment. Operator can monitor and control any sensor of the shop floor through a handheld sensor

dashboard at any time. Operator would get mostly decision-making task in a critical scenario. While designing interface, designer should be aware of scenario of use and task in hand. The mapping of relevant tasks and scenario are required for designing interfaces.

5) *Multimodality interaction:* Use of different mode of interaction in sensor dashboards like, voice-based commands, hand gesture-based interaction, touch-based interaction, etc. would create complexity for users in processing large amount of information. Processing multiple interaction information through multiple sensory channels would become complex for operator, especially in a complex scenario and difficult task. Because human has limited working memory capacity. According to Cowan, human can process maximum of 5 plus or minus 2 items at a time [22]. Therefore, designer needs to first look at the usefulness of interaction and its significance while designing sensor dashboard in an Industry 4.0 context.
6) *Interoperability:* It is the ability of a system to exchange information effectively and efficiently. Interoperability in Industry 4.0 opens up new opportunities to communicate between human to machine and machine to machine. The multiple system integration in a single handheld device/ software (sensor dashboard) increases the complexity of information flow and identification of machines in the production process [23]. Thus, interoperability feature of sensor dashboard increases complexity at system level design and thereby in interface design

These complexities should be considered by the designers while designing sensor dashboards in Industry 4.0 context.

VI. Conclusion

Industry 4.0 which is now an emerging concept has become a canopy terminology for a new industrial model that holds future industrial developments regarding CPPS, IoT, Robotics, Big Data, Cloud Manufacturing, VR and Augmented Reality. All of these technologies have put immense pressure on sensor dashboard designers for arranging information in more intelligent manner. The major challenge that the interface designer will face is the consolidation of all the information from different technologies and placing it on the dashboard in the most effective way, to sync the data from different technologies and finally to optimize the cognitive load of the dashboard users.

This paper discussed the needs of redesigning approach for complex sensor dashboard design for Industry 4.0 factories. Increased information becomes the main cause of interface complexity that interface designer needs to consider while designing sensor dashboard. Also, this paper reports six main challenges for designers. The six challenges help designers to synthesize their designs for improving the quality of sensor dashboard designs.

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