Human-Machine Interaction in Cyber-Physical Production Systems

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***Abstract*—As factories thrive to produce better and more precise products, the cognitive load increases and the factory workers performance starts to affect the results. This paper presents a possible solution that aims to help the assembly line workers by reducing their cognitive load when looking for the tasks they need to execute for each product and consequently help the business. The proposed solution focuses on a support interface designed to grab the worker's attention to the most important information and uses it to integrate the human in the loop of a Cyber-Physical System (CPS). In this paper, we present the architecture of the developed and constructed CPS, which contains the interface, a robotic arm and an artificial vision system.**

***Keywords*–CPPS; Support Interface; Cognitive Load; Expertise Level**

I. Introduction

As the manufacturing capacity of companies continues to grow, extending their variety spectrum, the workload felt by the human element of these production environment increases [1], and their situational awareness during the operation decreases. This solution has direct impact on the company's operators, since it is where the problem resettles and has an indirect change on the company's business. As for the assembly line operators, it is expected that, with the resolution of the presented problem, they are more attentive throughout the work shift leading to a more precise performance which will prompt a higher success rate and consequently boost their confidence and motivation. With a successful worker comes a successful business. Due to the reduced failure level from the operators, the company is able to produce more, faster and with a higher quality. This improvement will avoid human and material resources waste as the products will more likely get a positive grade when being evaluated by the quality assurance department.

There could be an enormous variety of combinations of tasks in each assembly station, which raises the probability of error if the operator is not certain of how and what set of tasks to complete to fulfill a specific product's requirements, and it can get worse if the factory is capable of producing a large number of different products. For each product that comes on the assembly line there is a list of tasks to be completed on each station on a short time lapse (around 3 minutes, for the PSA Group) and when there are multiple products in a row that require the same tasks the operator starts to ignore the screen because it is not clear that the tasks changed or the information has bad resolution [2] and simply performs the same tasks that completed on the previous product. Mistakes start to appear when suddenly a different product shows up on the assembly line and the operator was not able to identify the changes on the support interface. Most of this mistakes, come from the fact that the operator was not capable to detect the changes on the screen between each product that shows up because the interface was developed without taking into consideration the **cognitive load** of the employees, due to the long working shifts, neither their **expertise level**. In most production factories that contain an assembly line and require human intervention during the process, the working shifts can reach the 16 hours mark and a total of more than 60 hours a week, which is physically and mentally heavy [3], [4] so there is a need to reduce their mental effort when it comes to software that was created to assist the operator. Human operators should not be treated like machines nor expect that they preform like so as they will not perform proficiently as soon as they integrate the production line. There is a learning curve that must be taken into consideration and treated carefully. There is a need to redevelop the support interface system replacing the current one with another capable of adapting to the user's expertise level and also reduce the operator's mental effort when interacted with so that it really becomes a **Support Interface** instead of just a screen with information.

In Section 2 - Motivation and Related work, it is described the motivation to address the problem and some related work with this topic as well as the objective of the proposed. In Section 3 - Research question and proposed concept, the reader will be presented with the developed solution and all the aspects that where taken into account during its implementation related with the Interface. In Section 4 - Scenario, is where the CPS architecture, elements and sequence of activities are described and explained. During Section 5 Discussion, the reader is given a set of arguments that support the motivation for this problem's solution, some direct and indirect expected results with the developed approach and also a few restriction and frailties of the system. Finally on Section 6 - Conclusion, there is given a wrap up of the whole problem proposal and it's solution.

II. Motivation and related work

Modern production lines benefit from the Internet of Things (IoT) and Industrial Cyber Physical Systems (ICPS) technological advances to create environments where Smart Connected Products can influence its own production process and companies can benefit from Service Based business models [5].

With the Industry 4.0 appearance, the human integrates the CPS with its own Digital Twin representation, this way, not only the machines are aware of the existence of other machines but also of humans with which they can and must interact. This integration came from need to change the roles on the collaboration between both parts, from demanding an adaptation from the human operator to the machine [6], [7], to becoming the machine to adapt to the human. With the evolution of the manufacturing paradigm, balancing and changing the volume-variety relationship became a necessity. From Mass Production where factories produce large amount of similar products raising the volume and decreasing the variety, to the Mass Customization, increasing the product variety and reducing the volume manufactured of each model [8]. With this evolution, companies are more agile and capable of responding to the client's will which emphasizes the importance of the human intervention on the assembly line, bringing the human's flexibility to adjust to any expected and unexpected changes [9]. The interplay between humans and a CPS occurs either by direct manipulation, or with the help of a mediating user interface and it is best applied in a Cyber-Physical Production System (CPPS) which comes from the fusion of cyber, physical, and socio spaces through Industry 4.0 [10] and where the machines are responsible for performing the heavier and repetitive operations, while the human employees are responsible for handling shop-floor equipment and supervising processes for high-level decision making [6], aiming this way for the delivery of a high quality product, taking advantages of both human and machine's best attributes to complete a task.

Normally, workload and awareness issues are handled by changing the physical element's (robotic manipulator) autonomy levels, increasing them in order to ease the human operator's intervention. However we propose that changes are made to the support interface, and to the manner in which it is conveyed to the human operator, providing them with a tool that affects the operator workload and awareness in a positive fashion [11]. By now, we have identified the two unexplored variables to the development of a support interface for an assembly line worker. The main objective of this article is to contribute for an easier, more intuitive and adaptable interaction of the production line operator with the interface that provides all the tasks to be executed during the process as follows:

- **Providing the worker with an interface that is able to adapt itself to the the user's expertise and reduce cognitive load.**

This interface will be able to change based on the user's success rate over time which is gathered from an evaluation team that makes sure that every task was executed correctly. In order to have an adaptive interface and since this is inserted in a Cyber-Physical Production System, the system needs to know who is working at each shift which denotes to the need of having a virtual representation of each operator, creating a Digital Twin that will communicate with the remaining of the components as well as hold the information about the operator so that it can adapt the interface accordingly.

III. RESEARCH QUESTION AND PROPOSED CONCEPT

The interface is the main aspect of the presented article as it is the bridge between the Human and the remaining of the system, it is the machine with which the Human communicates and interacts.

As a way to identify the worker that is interacting with the interface, a simple login page was created where the worker has to insert a four digit login code that represents him in the system and from this point forward the system has all the required information to present the correct interface and the tasks that the worker is capable of executing.

The developed interface is mainly composed of "cards" that contain the information regarding each task that the worker must perform. The interface contains a top bar containing complementary information such as the Station in which the worker is working on and the stopwatch indicating how much time the worker has to finish the tasks for that product. Right below this top bar there is a section with a more relevant information about the product in construction showing the product's name and extra features if the product demands so, also in this section is placed the STOP and RESUME button.

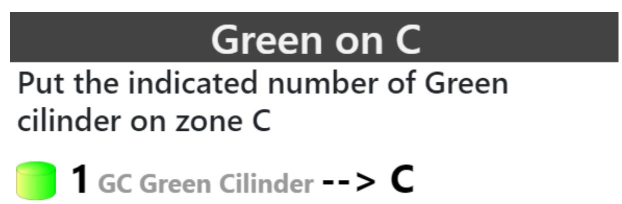

Figure 1: Card with information about the task

These "cards" (Figure 1) are essentially a rectangle where all the necessary information about the task is presented, containing the task's title on the top part of the card, the task's description right bellow the title where it is explained in a more extensive version how the task must be performed and after this description, a list with the necessary Assets is presented, indicating the quantity, code, name, image and the Zone's letter in which the worker must place the Asset if applied.

A. Grab user's attention

By researching about the topic [12], it was found a way of how one can grab the user's attention through an interface and using the acquired knowledge, Figures 2 and 3 where designed and developed in order to grab user's attention making sure he is aware of what is happening on the system.

Figure 2: Card with information about a task that is only present when an extra package is requested

The figure above represents a task that has to be executed and that is why it has the same structure as regular task. The only difference between the Figure 2 and Figure 1 is how frequently they appear on the screen. For this project it was defined a Default set of tasks that must be performed for every product that may show up for assembly and those tasks are presented has Figure 1 demonstrates. Whenever a product has a specific set of tasks that only belong to that product they are presented as Figure 2 by changing the border color to red that represents attention and caution and the title's background by adding a colored patterned as a way to enhance their appearance and grab the worker's attention to that new and different task that is crucial for that products overall correct assembly.

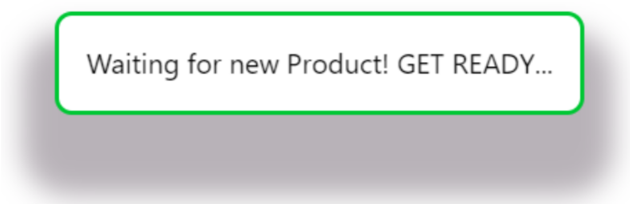

Figure 3: Message shown when waiting for the new product in line

While the Vision system is analysing the working area and the Robotic Arm is reaching out for the new box of assets, the worker is presented with the Message that Figure 3 is showing. This happens so that the user is aware that the product is complete and a new one is being prepared to get assembled and by clearing the interface, we are able to attract the user to the new information. This message is presented with a fat rounded green border passing out a feeling of success and achievement. Note that for this message it is used the Depth and Size illusions to get the user to absorb the most important information which in case would be the "GET READY" part of the message [13], [14], [15].

B. Cognitively Light Interface

In order to make all of the system's interfaces as light as possible for the worker, a list of suggestions was taken into consideration and used as a guide to design them. The interface contains a clear core area that contains the most relevant information and instructions which are simple and concise, as introduced before. Although there is a change on the interface regarding the level of expertise of a user, the format is consistent throughout the different interfaces either if the expertise level changes or if the tasks are unique for a product.

As to color schema, the taken approach was to keep the most relevant information with a darker color and the less important make it clear while having a white background.

C. Adaptive Interface

As it has been referred throughout the document, one of the goals of this proposal is to develop an interface that is able to adapt to the user's expertise level, and that, is accomplished by assigning an interface to each level of expertise available which for the tests environment it was defined as being three levels.

Although these three interfaces vary from one another, their changes are minimal keeping the fundamental structure intact avoiding a contrary effect from the one it is aimed for. This minimal changes rely on the format that the information is shown to the user regarding the assets as it is the only type of information that is flexible to changes.

TABLE I: FORMAT OF INFORMATION AVAILABLE FOR EACH LEVEL OF EXPERTISE

	Image	**Name**	**Code**
Novice	Yes	Yes	Yes
Intermediate	No	Yes	Yes
Expert	No	No	Yes

Table I gives us information of what is the format of the task's information that is presented for each expertise level. As it is visible, the **Novice** user is the one with less experience which means that it is the one who needs more support and so for each asset that is necessary for a task the card holds an image, the name and a code that represent the asset. For an **Intermediate** user, the asset is described with the name and the code, finally for an **Expert** user, the asset is only represented by it's code.

IV. Scenario

As a way to simulate an assembly line section as can be seen in an industrial environment, a small system was developed using the previously described interface, a robotic arm and a camera. This section describes how we were able to get as close as possible to a real world environment justifying the appearance of every intervener on the system.

A. Human-in-the-loop of CPPS

The architecture created to test the proposed solution, demonstrated on Figure 4, is divided into three main components each with a smart component (Digital Twin) [16] that represents it in the digital world and a forth smart component that is responsible for the connections between all the other

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three components and controls the action flow of the system and it is nominates Process Smart Component.

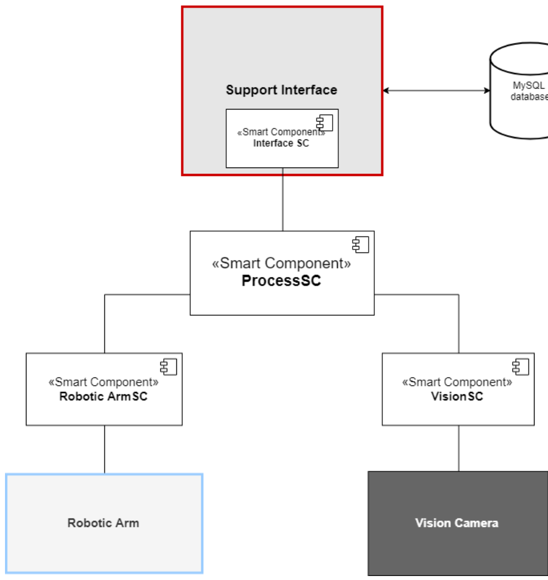

Figure 4: System's Architecture

The first component is the **Support interface** developed, with which the worker interacts where the tasks are displayed as the product progresses in the assembly line. The communication with the smart component happens every time a new product enters the station where the smart component sends an Id that represents the product, as well as the Time Period in milliseconds and the support interface communicates with a database where every task needed to be executed is provided and then displayed to the worker.

The second component is the **Robotic Arm** whose job is to deliver to the worker a box with every asset necessary to complete the tasks. For this component, the smart component is given the box position and the final position and the arm picks up the box and drops it at the final position where the worker starts to preform the tasks.

The final component present in the system is the **Vision Camera** that is responsible of verifying the tasks executed by the worker and rate them in a specific scale with which the algorithm will calculate the expertise level of the worker and consequently adjust the interface to the user.

B. Test the scenario

A solution found to test the System presented on Figure 4 has the following workflow:

1) Worker joins the Working Area
2) Worker enters user code
3) Robotic Arm moves assets box to near the worker
4) Interface shows tasks
5) Worker reads tasks
6) Worker executes tasks
7) Work time ends
8) Camera analyses the area
9) Repeats processes 3 to 8

The test case aims to simulate one Station of the production/assembly line from the moment a worker starts the working shift until the evaluation moment.

In this process, the worker must execute all the tasks presented on the **Interface** by placing the assets on the different areas defined, within the **Time Period** previously defined and shown on the interface in a countdown format. The process starts when the user enters the working station and enters his user code, after this, the **Interface** receives the Product being assembled at the time and gets all the tasks associated with it from the database, ate the same time, the **Robotic Arm** grabs the **Box** with the Assets and gives it to the user. At this point, the user has gathered all the conditions to start executing the tasks. When the time ends, the **Vision Camera** analyses the **Table Area** and verifies the final result. In case of emergency, i.e, the time is ending and the user feels that he wont be able to finis the tasks, the user has the ability to press the **STOP** button which will stop the whole system including the **Robotic Arm** and **Timer**.

C. How it works

Now that the actions flow for a proper test was presented we may go a step further on understanding what is actually happening "behind the scenes" concerning the communications and logic associated with the previously described actions flow.

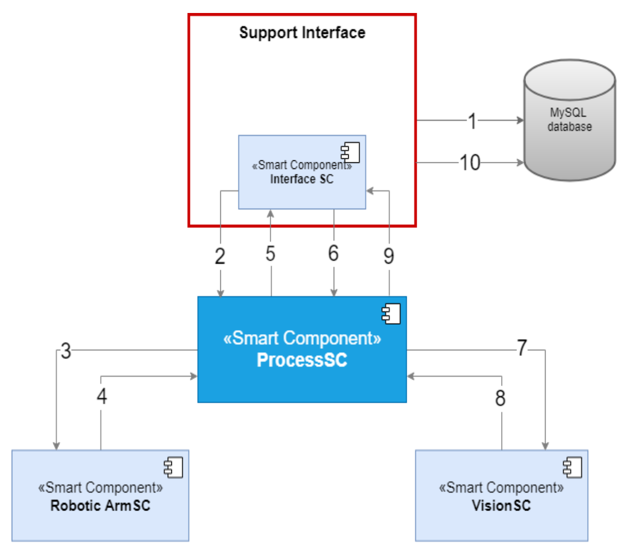

Figure 5: Flow connections between smart components

The above Figure 5 is composed of all the components of the system that are evolved with the communications that happen during the test execution, each arrow represents one of those communications and it's numerations indicate the data flow throughout the test case.

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1) User Login;
2) **Interface** tells the **Process Component** that the user is ready and the system may start;
3) The **Process Component** tells the **Robotic Arm** to start the movement;
4) The **Robotic Arm** informs that the movement is complete;
5) The **Process Component** tells the interface which product is being assembled and how much time the worker has and so show the tasks to the worker;
6) The **Interface** indicates that the time has terminated;
7) The **Process Component** tells the **Vision system** to start analysing;
8) The **Vision system** answers with the objects position on the working area;
9) The **Process Component** passes it out to the **Interface**;
10) The **Interface** saves the evaluation rate of the tasks after comparing the objects real positions with the expected ones.

Besides these, there are two other connections that can happen at any time during the system's execution and they are activated by the worker when the Emergency button is pressed. This button is implemented on the Interface to simulate the Emergency Stop Handle that is available throughout the entire assembly line as a last minute resource if the worker feels that he will not be able to complete all the tasks in time and the whole system must freeze. For so there are two complementary connections between the **Interface** and the **Process Component**:

1) The **Interface** indicates that the emergency button was clicked to STOP;
2) The **Interface** indicates that the emergency button was clicked to RESUME

V. DISCUSSION

With the developed support interface, the main goal is to affect in a positive manner the way the assembly line workers do their job and this way, as a result of the workers improvement, contribute for the success of the business in which it is inserted. This interface was developed having in mind the workers, their cognitive effort and their expertise level as these are two of many other factors that influence the worker's performance. With the Cognitively Light approach to the interface the main goal is to reduce the user's precious effort when reading from it and this way keep them more focus throughout the whole working shift which itself is mentally and physically demanding. The Expertise side of this solution brings a huge advantage to the workflow of the production line as a whole as it helps new employees to better integrate the production line and the same way bring the best of the expert worker's performance by adjusting the way the information is presented making it easy for novices and fast for experts.

With this solution implementation in a production line environment there are a group of aspects that are expected to improve either directly or indirectly. Are considered **Direct improvements** any positive aspect related with the production line workers and **Indirect improvements** any better aspect associated with the factory and company in which this solution is implemented. Here are the expected positive topics:

Direct improvements:

- Higher motivated workers
- More focus workers
- More energized workers

Indirect improvements:

- Faster production
- Less waste
- Happier clients
- More production variety

The presented interface was designed and developed having in mind that it could be used by any type of user with full mental and physical capabilities, regardless their gender, age our ability with technology and that is why the it was thought to have the least input from the user as possible, making it an almost read only interface.

A. Restrictions/Frailties of the CPS

As everything in the world, this CPS also has a few restrictions and frailties from each component on the system that limit the tests and consequently delay the evolution process demanding a higher number of tests and participants since the tests complexity is also limited.

Interface:

- Requires user input from external mouse controller;

Robotic Arm:

- Maximum payload weight of 5 kilograms;
- Maximum reach 0,85 meters;

Artificial Vision system:

- Only able to detect Yellow, Green and Blue objects;
- Not able to distinguish objects by their shape;

The described restriction are related to the current state of the Cyber Physical System (CPS) which could be improved with extra implementations.

VI. CONCLUSION

Expertise and cognitive levels are two of many aspects that influence a worker's performance and with the presented article we are introduced to a new approach for the support interface that guides the workers throughout the assembly process that helps to reduce the cognitive level and adapt to the expertise and this way help to grow the business. By bringing the worker to the CPPS and enabling a digital communication between him and the rest of the system it is possible to adapt the machines to the humans. Throughout this article, the reader is presented with the design of this support interface and a proposal of a CPS in which the human is part of.

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