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Procedia CIRP 112 (2022) 209–213

www.elsevier.com/locate/procedia

15th CIRP Conference on Intelligent Computation in Manufacturing Engineering, Gulf of Naples, Italy

Short-Time Adaption and Reconfiguration of Cyber-Physical Production Systems

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Abstract

Modern production systems are characterized by the increasingly use of CPS and IoT networks. However, processing the available information for adaptation and reconfiguration often occurs in relatively large time cycles. It thus does not take advantage of the optimization potential available in the short term. In this paper, a concept is presented that, considering the process information of the individual heterogeneous system elements, detects optimization potentials and performs or proposes adaptation or reconfiguration. The concept is evaluated utilizing a case study in a learning factory. The resulting system thus enables better exploitation of the potentials of the CPPS

Keywords: Ontology;CPPS;CPS

1. Introduction

Production systems are increasingly transforming beneath technological developments towards smart production systems, characterized by extending the use of cyber-physical systems and IoT networks [1]. Through these technologies, systems should better respond to external or internal changes and meet increased demand for flexibility. Adaptations to the changes are made either by centralized optimization approaches [2] or by, e.g., decentralized (self-) adaptations [3, 4] of the individual system elements. Although an extensive discussion on the necessity of these adaptations exists in the literature [5-9], there has been little discourse on the structure and functionality of adaptation models. In the following paper, a conceptual model for the construction of an adaptation logic, in particular considering the short-term adaptations, is presented and illustrated by a use case.

2. Introduction

2.1. Adaptation versus structural change

Adaptations may be distinguished into adaptations and structural changes (see Fig. 1).

In the case of the adaptation type, the systems are changed with optimization within an existing flexibility corridor. The flexibility corridor is defined as an achievable interval related to different key performance indicators, which may be derived from the individual flexibility criteria [10, 11].

2.2. Optimization strategy

The optimization always requires the orientation on one respectively more parameters regarding minimization or maximization. In order to achieve the optimum, three solution classes can be derived analogously to the organizational theory [13] respectively to the general strategic management.

10.1016/j.procir.2022.09.074

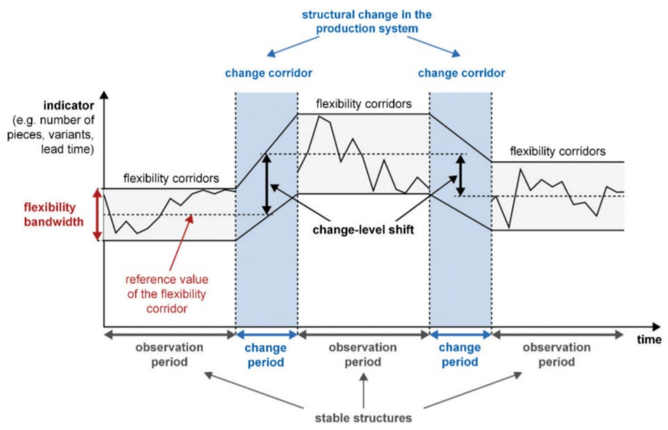

Fig. 1. Modelling adaptability (Source [12])

- the singular strategy ("one best way"),
- the contingency approach ("One best way for each given situation") and
- the configuration approach ("Many but limited configurations") [14].

The singular strategy ("fixed-configuration") is insufficient and not promising for smart production systems since this approach cannot or only inadequately represent the required flexibility within cyber-physical production systems.

With the contingency approach, only one (!) configuration with assigned parameter variables is selected from a continuous (contingent) system of variables ("Cartesian Approach"). This configuration is classified as the best configuration and is the preferred variant based on the evaluation function.

The configuration approach provides several but limited configurations for the optimization respective for the development of the system. Each of these configurations is feasible and fulfills the requirements in an overall holistic picture, differentiated from the entirely determined contingency approach. The configurations are called "Archetypes" [15] or "Gestalts" [16], depending on the application area.

2.3. Decision models for adaptions

Besides the optimization strategy, the decisive factors are where, when, and how the decision on adaptation or reconfiguration is made.

Although decentralized decision-making can be regarded as a design principle of Industry 4.0 solutions [17, 18], some centralized decision-making elements can still be found in existing solutions due to the system components' different maturity levels and technical characteristics. Furthermore, the controllability of purely decentralized decision systems is considerably more complex than in centralized decision systems, which in practice leads to the design of partially decentralized decision systems and thus to partially autonomous or autonomous systems [19].

2.4. Decision models for adaptions

Alongside the structural dimension, the temporal aspects of adaptation or reconfiguration are essential as well. The temporal dimension ranges from brief time units (in extreme cases even real-time [20]) to medium time units (shifts, days). The possible time frames for the adaptations determine the technical possibilities (fixed adaptation logic, simulations, or AI-based approaches) for selecting an adaptation or a reconfiguration.

3. Introduction

The adaptation or reconfiguration of the Cyber-Physical Production System is based on the underlying conceptual models, respectively, the system's architecture.

3.1. Cyber-Physical-System-Architecture

The envisioned approach is based on the following conceptual model, whereas the Cyber-Physical System consists of the elements:

- Observer
- Explanator
- Evaluator
- Decision Making
- Executer and
- Actuator

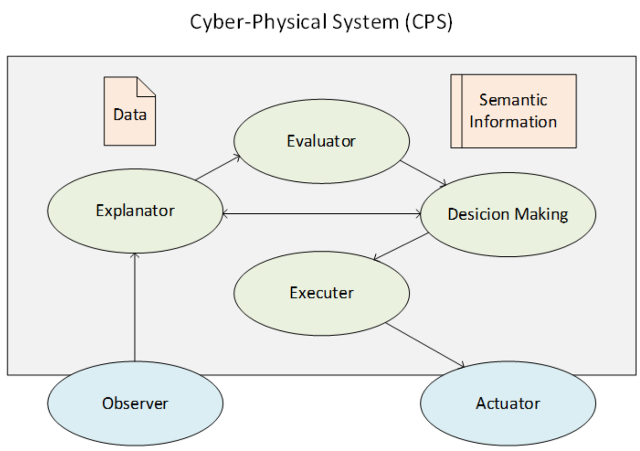

Fig. 2. CPS architecture

The Observer handles the perception scope. All information relevant for adaptation is recorded via the Observer and, depending on the application, also stored within the CPS.

In the Explanator, an explanation based on the information from the Observer and the semantic information using a static (e.g., exception-based) or dynamic (system-dynamic-based) explanation model is provided. The explanation forms the basis for the further structured initiation of an adaptation.

Through the evaluator, the particular situation is evaluated. The evaluation can range from simple models to multi-criteria [21] models.

The Decision Maker is now used to select the decision to be executed. The decisions include at least the basic options "Wait," "Parameter adjustments," "Configuration change," and "Delegation." The options parameter adjustment corresponds to an adaptation within the given flexibility space whereby the configuration change option represents a reconfiguration.

After the decision is made, the initiation of the decision with the derived and necessary actions is carried out via the Executor. The Executor transmits the necessary interventions to the Actuator, which performs the actual execution either in the form of an actual change of the parameters or in the transmission to other systems, such as other CPSs or a superordinate system.

After the decision is made, the initiation of the decision with the derived and necessary actions is done via the Executor. The Executor transmits the necessary actions to the Actuator, which takes over the actual execution either in the form of an actual change of the parameters or in the transmission to other systems, such as other CPS or a higher-level system.

3.2. Cyber-Physical Production Systems (CPPS) as a self-similar CPS system

The CPPS can be structured as a self-similar system [22] to the CPS. However, the individual system components are partially assigned to both first-order and second-order tasks. For example, the system component Observer in the CPPS can perceive both direct information from the process and information from other CPSs, as well as information from other CPSs, which in turn perform the actual perception. Analogous to the system elements with direct connection to physical reality (Observer, Actuator), the purely information-oriented system components (Explanator, Evaluator, Decision Making, Executor) also consist of.

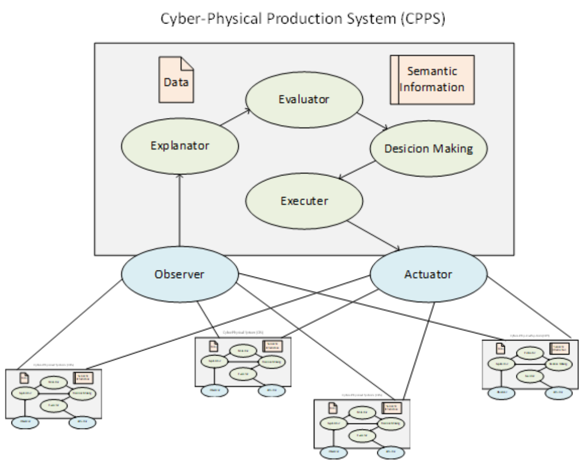

Fig. 3. CPPS as self-similar CPS system

3.3. Adaptation and reconfiguration process

Based on the structure, the adaptation or reconfiguration process now takes place in the following steps for a defined configuration, where a configuration is understood to be a well-defined instance $C_i = \{Exp_j, Eva_k, Des_l, Exe_m\}$ consisting of a set of Explanator, Evaluator, Decision Maker, and Executer

- determination of deviation (Observer)
- explanation of the deviation (Explanator)
- evaluation of alternative actions (Evaluator)
- selection of the alternative action (decision making)
- initiation of adaptation or reconfiguration (Executor)
- execution of the adaptation or reconfiguration (Actuator)

Each CPS and each CPPS has several permissible configurations, which in turn are realized by a digital image of each configuration as a Digital CPS Configuration-Twin or Digital CPPS Configuration-Twin. Using these digital twins, individual measures derived from the explanatory model can be simulated concerning their effect on the target variables. The simulation can be based on different functional approaches (e.g., classical simulation modeling, agent-oriented modeling, AI-oriented modeling).

4. Use case: Werk150 scooter production

The following use case uses the example of a collaborative workstation within a scooter production Werk150 to describe how the adaptation process described can be applied. In the use case, the reaction to a change in performance is as follows.

4.1. Initial situation

In Werk150, there are collaborative workstations, which consist of a human-machine team. For the use case, the picking station is considered. This workstation is responsible for providing materials for production. The human and the cobot perform the loading process with different picking and placing actions. In this context, the station is modeled as a CPS within a CPPS. There are also the associated digital twins.

4.2. Use case

Within the CPPS, the performance for the processing of a work step is recorded. A deviation of the actual time from the target time is detected for the picking station. The observer within the CPS detects this difference and initiates the adaptation process.

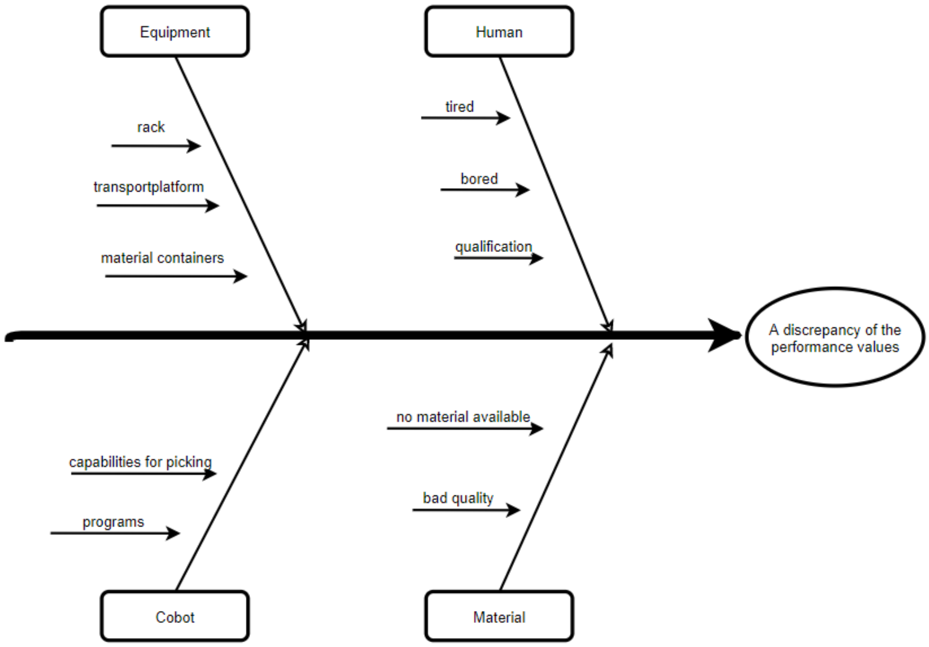

Fig. 4. Ishikawa diagram for a discrepency of the performance values

4.3. Adaptations for the picking station in Werk150

The Observer of the CPS Picking Station detects a deviation, which is forwarded to the Explanator. The Explanator contains possible causes and their effects for various problems. Figure 4 shows an expression for the discrepency of the performance values.

The explorer has access to the data from the CPPS and the measured values that the CPS can record. In combining the measured data, the semantic information on the data, and the stored explanation model for a deviation in the performance values, the explorer can now determine possible causes and pass these on to the evaluator. In the use case, the explorer can exclude availability for the material branch since the material is available. For the human being, he can exclude the qualification since he is qualified for the activity. Through further measurements and queries, the possible explanations are reduced to employee fatigue, boredom for the employee, problems with the execution of the programs at the cobot, and problems with the shelf setup. This subset is now passed on to the evaluator.

The evaluator now evaluates the possible action alternatives for the passed subset of possible explanations. In this case, he arrives at the action alternative that the employee needs a break.

The action alternatives are now passed on to the decision-making process. The decision-maker now selects an action based on the scoring of the action alternatives. In this case, it selects the action "configuration change." In this way, the employee is sent on break for a defined time. This result is forwarded to the Executer.

The Executer now carries out the steps necessary for the action. In this case, the employee must be informed. Furthermore, a signal must be sent to the cobot. These steps are sent to the Actuator.

The Actuator implements the steps of the executor within the CPPS. In this case, the employee is signaled via the terminal that he should take a break. The cobot is sent the information to buffer the execution and to resume work after the break.

5. Conclusion

The existing use case shows the mapping of adaptation and reconfiguration based on the general CPS/CPPS model. By including configurations, the provision of several equal optimization approaches was structurally enabled for the first time. In particular, the level partitioning provides an architectural framework for the individual aspects of adaptation or reconfiguration. Extended use cases further evaluate the model in the smart factory. In addition to expanding the individual levels, there is a need for further research and development about mapping in the CPPS.

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