Test Case Selection for Networked Production Systems

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***Abstract*— This paper provides a discussion on the coming technological changes in process automation of networked production systems, which will change the testing procedure. In the smart factory of the future there will be no possibility to reach a test coverage of 100%, assuming a flexible automation with continuous reconfiguration and dynamic changes during runtime. Consequently, large amounts of test cases and powerful algorithms for their prioritization are needed in order to certify the correct functionality of the production systems in the network. A concept is presented on how to analyze and prioritize the enormous amount of test cases resulting from the changes during runtime. The proposed approach for test case selection utilizes information of the product, the process and the status of the production machine for the prioritization and selection.**

***Index Terms*—test case selection, functional testing, test prioritizing, quality-assurance, smart factory, networked systems**

I. Introduction

In the recent years the requirements of customers have changed as the demand for new, individual products is growing. The market is reacting with shorter innovation cycles and a larger number of individualized products. This increases the amount of product variants and reduces the volumes, i.e. quantities.

Especially industrial nations are struggling with high personnel costs resulting from the changing demands towards a flexible variant production, which is today labor intensive. In order to be able to handle these challenges new automation technologies need to be engaged [1]. Thereby, software is increasingly moving at all levels of automation systems from the management level to the field level enhancing the flexibility and providing plug and produce functionality. Manufacturing systems and services are being connected via a worldwide open communication network which is enables a flexible automated production [1].

Due to small batch sizes, the number of reconfigurations will increase and the composition of production networks based on multiple systems configuration will change constantly. It is required that production systems can connect to ad-hoc networks in the sense of cooperating and coordinating the manufacturing steps to produce a one-of-a-kind product or small batches. Those changes towards Smart Factories cause the production systems which are rather “static” to become dynamic networks of production systems [2].

However, to ensure the correct functionality of the production systems and with it the quality of the products being produced, new test concepts are necessary. After all the production systems and machinery is utilized in a changing context of the production network and in different ways of the ad-hoc configurations. Significantly, more test cases are required to cover all functionalities of the production systems and their multiple usage in the ad-hoc networked production. This is apparent as there is a large amount of heterogeneous machinery with complex interaction between software, electronics and mechanical systems [3]. In order to guarantee the correct functionality of a new permutation of the manufacturing network, extensive tests are required prior to the start of production. Due to limited resources and time, it is not feasible to execute all test cases to a 100% after any reconfiguration of the dynamic system. Obviously, it is important to select effective test cases for an effective test and high coverage.

This paper proposes an approach how to prioritize and select necessary test cases for networked production systems which undergo reconfigurations during run time. First the technical realization of a smart production and the resulting challenges for testing to ensure the correct functionality of production systems are described. Afterwards the concept of how to select necessary test cases is introduced and its realization and verification presented.

II. State of the Art

A. *The Technological Changes of a Smart Production*

The vision of a networked production in a smart factory describes the worldwide networking of production systems. The networking can be categorized in the horizontal and the vertical integration [4]. Horizontal integration describes the connection between cyber physical production systems on the same layer of the automation pyramid via worldwide networks e.g. between different production systems. The vertical integration describes the consistent integration between several layers of the automation hierarchy. This enables the direct communication between the field level and the enterprise resource planning level or a cloud. This can among other things be useful for diagnostic reasons.

Every cyber physical production system as well as every product being produced owns a virtual representative who substitutes the physical production system in the virtual world.

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It offers services which the production machine can execute and negotiates with the representative of the product being produced and the infrastructure [3]. To reduce the complexity for the operators caused by the networking of the production systems, the systems must provide self-X properties. That includes the Plug & Produce capability. It should be possible to connect production systems ad-hoc without manual configurations necessary. To realize this seamless integration a certain degree of autonomy has to be integrated in the production system to announce itself to the environment and initiate service offers. Depending on the manufacturers and the layers within the automation pyramid there are many different protocols, semantic descriptions, interfaces, operation systems and programs. A cooperating network has to deal with this heterogeneous environment.

B. Impacts on Testing

The networking of production systems is changing the production fundamentally. As listed in Fig. 1, there are new challenges emerging to ensure the correct functionality of networked production systems.

Nowadays, tests are executed in the engineering phase of production systems and have been accomplished with a commissioning test (see Fig. 2). In operation, the production system produces a large number of the same product with the same configuration and just quality control activities are necessary. Due to the inflexibility of usual automated production machines the facility major reconstruction measures are necessary when new product types shall be produced. This results in a temporary decommissioning while re-build and configuration measures are performed, followed by commissioning tests before getting back in operation.

The operational sequence in the factory of the future will change fundamentally. In order to avoid unnecessary downtimes for re-build measures, flexible machines that are capable of carrying out reconfiguration during the operation are required. These reconfigurations can be software updates on the fly, the execution of different software components as well as mechanical reconfigurations by changing tools or cooperating with different components. When the environment changes, regression tests are necessary to assure the correct functionality of the facility. This leads to the fact, that quality assurance isn't sufficient in the operation period anymore. This shifts the testing increasingly into the operation phase (see Fig. 2).

The expected proliferation of necessary tests in the operation period gives rise to new questions like: How to manage the huge amount of test cases caused by reconfigurations? How to use limited test resources efficiently?

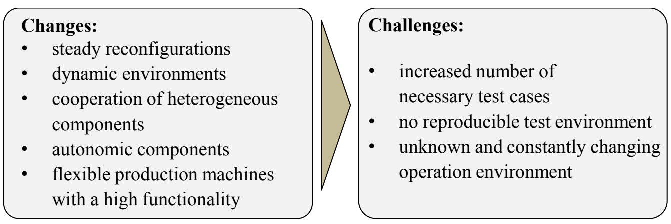

Fig. 1. Changes in production and the resulting challenges

How to perform testing without affecting the operation too much? How to test machines that haven't been constructed particularly for a specific product type? Those questions have to be answered by new test concepts.

There are already some concepts how to handle parts of this problems. Regarding the testing of networked heterogeneous systems, there are different approaches concerning networked consumer products, how to minimize time and resources to test cyber physical systems in test beds before deploying them to the market [5,6].

Common test selection concepts regard functional aspects like the maximizing of coverage of the paths, branches or statements with acceptable effort. A methodology of regression testing of configuration changes is described in [7]. Other test case prioritization concepts are based on assessment of an expert and influence models [8]. In contrast to concepts regarding the testing of networked consumer products, networked production systems provide more possibilities for acquiring data.

III. Concept for Test Case Selection

This concept proposes to use new sources of data as an input for the prioritization algorithm. These are available through the vertical and horizontal integration of networked production systems. Functional as well as nonfunctional information can be shared to select suitable test cases. Functional information concerns the actual state of the production system as well as the functional requirements of the product and the process. Nonfunctional requirements concern for example the degree of value added or the delivery date.

To describe a production step, information about the product, process and resource is required. By bringing this information together it's possible to make a statement about the reliability of the next work step. This estimated reliability is compared with the maximum tolerated reject rate. This constitutes the measure if tests are necessary.

The relation of the information sources is illustrated in Fig. 3. The functional and nonfunctional requirements of the product are substituted by its virtual representative. As pointed out in Fig. 3, this information can be a demanded accuracy, a delivery date, an ecological aspect and the costs already incurred. Information about the subsequent process like the ecological aspect and criticality as well as practical knowledge is provided by the representative of the process. With the help of this information the maximum tolerated rejection rate is calculated.

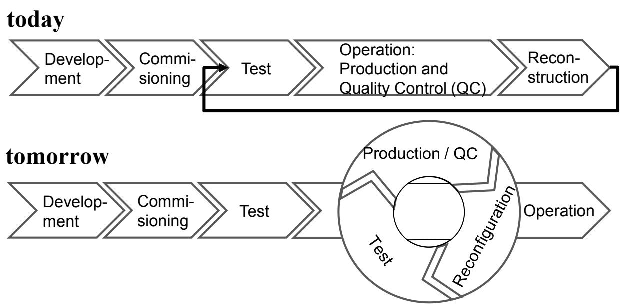

Fig. 2. Lifecycle of production facilities

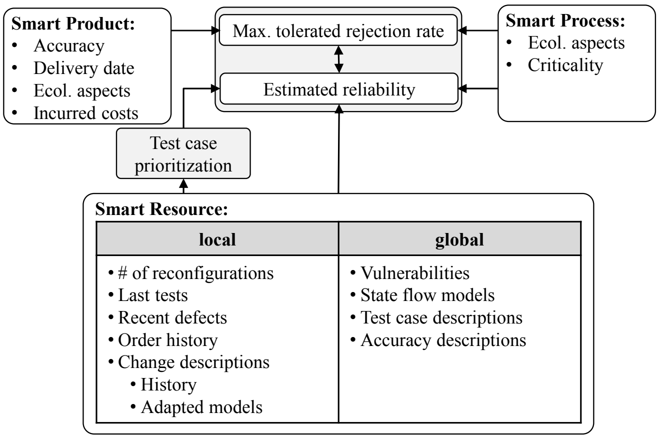

Fig. 3. Overview on the structural build-up of the test selection concept

Due to vertical and horizontal integration, networked production systems are a huge source for acquiring data, which can be used for prioritizing important test cases. The data can be divided in two types, global and local information. Global information is general anonymized data about the behavior of the resource type. The data are saved in open databases, which are filled by resources of that specific type all around the world like typical errors and the assumed energy consumption. Local data is related to the specific resource and saved in private databases. This concerns the unit specific information like the numbers and kinds of reconfigurations executed in recent time. The history knowledge contains information on type and date of test cases that have been executed as well as on defects that have been occurred, product types that have been produced and types of reconfigurations that have been executed. The global data includes typical defect types, plant models on different abstraction levels as well as descriptions about available test cases in test suites. The descriptions of the test cases contain the test models, costs, effort and the impact on operation when executing the test cases. By merging this information on the resource and the criticality of the process, the reliability of the resource can be estimated.

The maximum tolerable rejection rate of the resource is compared with the estimated rejection rate. As the reliability of the resource is too low for the upcoming work step, test cases have to be performed to increase the reliability estimation of that resource. In order to select the most suitable test case, the available test cases are rated and prioritized according to a cost benefit analysis, i.e. the degree they increase the reliability compared to the effort they cause. The increasing of reliability depends on the date of the last tests, the test coverage of the paths which are affected by the reconfigurations as well as the criticality and the likelihood of occurrence of concerned functions. When the estimated reliability reaches a threshold, by performing suitable tests, the subsequent process step may be executed.

IV. Realization

A. Scenario

A toy car shall be produced in a networked production. The process steps are presented in Fig. 4. The basic product, a sheet, is being formed by a press. The resulting product, the raw body of the toy car, is painted by a paint machine. In the last process step, the toy car, is assembled by pinning the painted body on a chassis by a handling machine. The necessary information for the selection algorithm is represented in speech bubbles. The work piece carrier of the toy car is shown three times when negotiating with the corresponding resource in chronological order. The value of the product in the first work step is with 4€ considerably low. Due to the specification of the product and the process the calculated maximum rejection rate results in 5%. As the last tests of the press machine have been carried out recently and just a few reconfigurations have been performed, a rejection is estimated by 0.5%. The requirements of the reliance of the resource are fulfilled and the work step can be executed without further testing. Value is added by the pressing work step, so the incurred costs of the product increases to 7€. This and the ecological aspect of the next process step lower the maximum defection rate to 3% for the next work step. The paint shop hasn't been tested for a longer period, this causes the estimated rejection rate to rise to 6%. The selection algorithm prioritizes the available test cases by doing a cost-benefit. After executing the recommended test case, which e.g. checks if the nozzle has dried up, the estimated rejection drops to 2% and the raw body can be painted. The ecological aspect of the product has raised because of the energy that has already been put into the production. Considering the early delivery date in 2 days, the ecological aspect as well as the incurred costs of 14€ the maximum rejection rate results in 1%. It's known that the axes of the handling machine have been misaligned in recent time, which results in an approximated rejection rate of 6%. Suitable test cases concerning the axes calibration are selected and executed before mounting the painted body on the chassis.

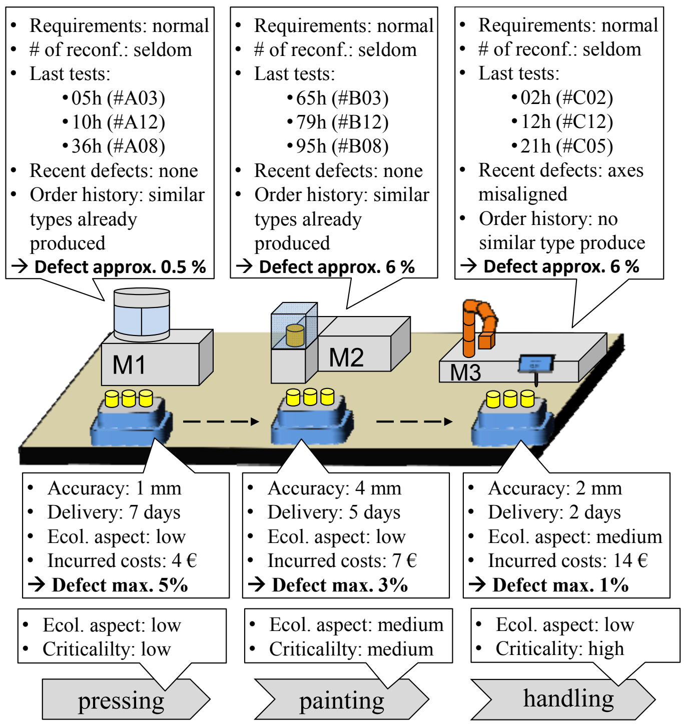

Fig. 4. Scenario of the test case selection of a toy car production

B. Implementation

To demonstrate the concept, a flexible, decentralized assembly plant was developed. This networked production system is able to produce designed LEGO cars individually. An input station, two handling stations and a pressing station have been built for this purpose. The handling stations place bricks on the work piece carrier, which are fixed by the pressing station.

The structure corresponds to common concepts of a flexible networked production. The product as well as the production systems are represented by virtual representatives which access process information and negotiate on the next work steps. The virtual representative of the product is aware of its actual state, the target state, the delivery date as well as a defined priority and product quality. The stored process data contains occurring difficulties of process execution as well as an approximated energy consumption. The virtual representative of the resources has access to databases, which are updated constantly by process information of the resources. Although the composition with three different production systems seems pretty easy, many occurred faults are caused by the dynamic interactions which are hard to locate because of its decentralized and flexible structure. First investigations have shown that these kinds of faults are hard to avoid because the production systems are tested isolated or in a static environment. For detecting and localizing these kinds of errors, the demonstrator is currently expanded with different features.

System models describing the behavior of the resources are developed for analyzing the path coverage. Furthermore, a test suite to test the resources automatically is developed. To increase the test opportunities active test work piece carriers are developed to interact with the resource in a test procedure. Three new types of resources are in the construction as well as more resources of the same kind to get redundancy.

C. Verification

When completed, the 9 production systems can be installed individually on 9 different slots which enables around $2.5 \cdot 10^8$ permutations resulting in a highly dynamic environment. Fig. 5 illustrates the inputs for the selection algorithms provided by the representatives of the product, process and resource by the example of a handling process. The specifications of the car are set in advance. The procedure corresponds with the scenario described. If the reliability of the resource is too low, appropriate test cases will be carried out before executing the work step. These test cases can be executed by the production machine independently or in cooperation with a test work piece carrier or another resource. The redundant resources will feed a global database with anonymized data for detecting typical defect types of this kind of production system.

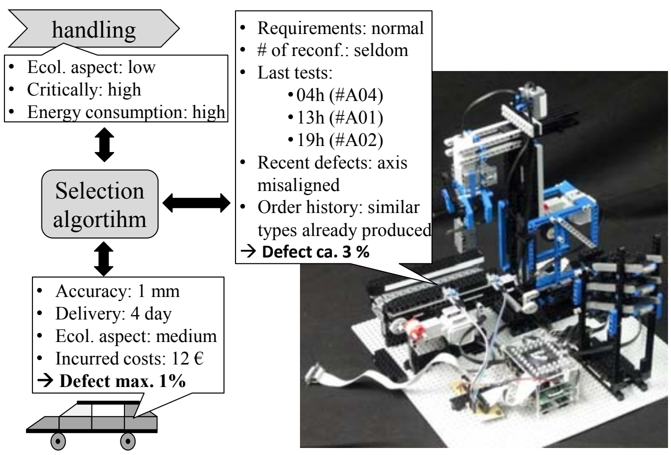

Fig. 5. Scenario of the test case selection of a handling process

Investigation shall be performed, where the fault detection rate and the required effort of this concept is compared with a test coverage of 100% and another usual test selection algorithm which just regards the path coverage and not the requirements of the product.

V. CONCLUSION

First investigations with a demonstrator have shown that there is a need for new test selection concepts to handle the changes in the production.

The concept uses new information sources to prioritize and select suitable test cases. Due to the digitalization and networking of production, there are metadata available about the production which can be used to enhance the test case selection process. This comprises functional as well as nonfunctional specifications of the product, process and resource. In comparison to current selection algorithms, this approach also regards the needs of the ever changing product types by using functional as well as nonfunctional specifications, like the already incurred costs or the delivery date, to order-specifically decide if test cases are necessary or the risk of a reject can be tolerated. This is done by a cost-benefit analysis. It’s assumed that order-specific inputs enable the selection algorithms to prioritize test cases more effectively by responding to the requirements of the product.

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