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Manufacturing System Upgrade with Wireless and Distributed Automation

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Abstract

This paper presents a case study of developing a distributed factory automation system model upgrade with decentralized control deployed on a network of six programmable automation controllers communicating wirelessly. The goal is to develop a distributed system which is flexible enough, and easier to reconfigure with on-the-fly online software updates in a smart factory automation environment. Our approach benefits mainly production industries which require a robust and modular software design requiring less effort for their production line. The developed solution aims at flexibility, re-configurability, ease of maintenance and reduced downtime costs.

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Keywords: Distributed automation, IEC 61499, dynamic software updates, wireless networking, flexibility

1. Introduction

The future manufacturing concepts that are actively being developed worldwide, aim at higher degrees of flexibility, achieved through intelligent automation. Many vendors nowadays are moving toward modular and distributed architectures of automation systems, since it greatly simplifies system engineering processes, provides

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flexibility, upgrade extensions, and interoperability across multiple vendors [10]. This, in turn requires to take advantage of the industrial Internet architecture, in which manufacturing machines have many communicating measurement and control devices, and production lines and factories combine these local networks into a "production Internet".

While majority of automation systems use programmable automation controllers (PAC) and their programming standard IEC 61131-3, its deficiencies for distributed systems implementation gave rise to a new standard IEC 61499 that is emerging to address future factories requirements commonly associated with such approaches as Industrie 4.0. IEC 61499 standard provides capabilities far beyond those widely used in the industry. IEC 61499 compliant applications offer the benefits in saving the time and the effort needed to develop a distributed automation software [9].

Implementing and converting a centralized control application to a distributed application in the traditional standards such as IEC 61131-3 would require: the global shared variables for communication, assigning of the execution order to the Function Blocks (FB's), and careful planning of each hardware scan cycles of the network devices [6]. However, this process is quite simple and flexible in IEC 61499 standard where the distribution of the application is provided within the standard itself. The IEC 61499 distributed automation architecture provides a modular application development environment using Function blocks (FBs). The standard allows the decentralized distributed intelligence to be built as a part of application development process [9], enabling easy distribution, interoperability, and re-configurability [8]. Distributed application development using IEC 61499, anticipate a growth in providing flexibility, re-configurability, scalability, ease of use, and economic efficiency to existing systems [7]. Redesign of traditional automation systems with centralised logic into fully distributed logic e.g. [12] is being widely investigated, e.g. [11]. The design patterns have been developed for this purpose, e.g. [13-16]. Wireless communication simplifies integration, reconfiguration and commissioning which explains the growing interest to it in manufacturing. Wireless distributed system could also provide additional benefits of maintenance and reconfiguration from remote locations. A challenge of distributed design includes its verification, and there is ongoing works on enhanced verification frameworks, such as formal verification [17-18].

In this paper, we investigate a case of upgrading a manufacturing system model with new mechanical capabilities and new automation system. The case study includes modification of the mechanical plant and migration of the automation system software to a new, much more distributed hardware configuration with wireless communication. The original EnAS demonstrator [2] (a small scale multi-conveyor material handling system demonstrator) has been developed a decade ago and was equipped with a heterogeneous network of two IEC 61499 compliant controller prototypes NetMaster and WAGO, each responsible for a half of the model production line. The upgrade included changing the controllers to a network of 6 much more modern programmable automation controllers (PAC) nxtDCSmini commercially produced by an Austrian company nxtControl.

The paper is organized as follows. Section 1 provides introduction to the topic. Section 2 describes the modification details of the EnAS [2] workbench and its operations and configuration. Section 3 provides details about the control software architecture. Section 4 presents software deployment as a distributed application on the wired and wireless configurations. Section 4 discusses deployment of the software to different hardware configurations. Finally, Section 5 concludes the paper.

2. EnAS Material Handling Demonstrator Configurations

The EnAS system is shown in Fig. 1. It is a simple assembly system model consisted of six conveyors, two jack stations, two grippers and ten sensors. The six conveyors move three pallets sections. The pallet on the conveyor, transfers a can filled with the work workpiece and covered with a cap.

The individual conveyor belt sections are driven by an electrical motor which moves the pallet in clockwise direction. The pallet is stopped at the various loading and unloading stations by means of selective switching of the conveyor belt sections. The conveyor belt on each side of the demonstrator consists of three independent conveyors, each driven by a motor with a clockwise rotation on the underside. Thus, the pallet on the conveyor belt always moves clockwise when the motor is activated. Each pallet consists of two small and two large slots. The smaller slots are for the cans and the larger slots are for the covers which sit on top of the cans. The cans and the covers are combined into a closed package. Each pallet can transport a maximum of two aluminium cans and their covers.

The EnAS system was upgraded with the nxtDCSmini devices. Each of the nxtDCSmini devices can be connected to a wired or a wireless connection. Furthermore, a second manifold has been installed on the other side of the demonstrator for controlling jack station 2, sledge 2 and gripper 2. The outer frame of the demonstrator forms the conveyor belt on which several object carriers or pallets are transported.

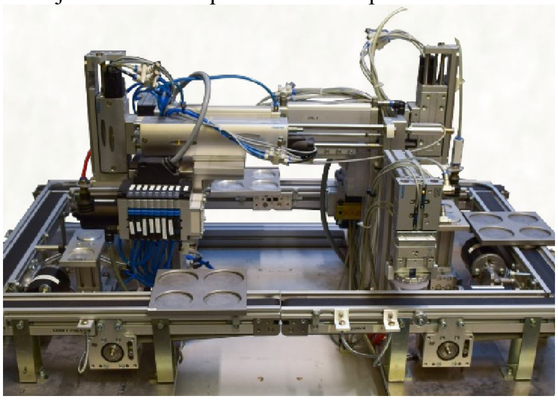

Fig.1. EnAS Workstation.

In the new upgraded version inputs and outputs from the sensors and actuators are interfaced to six distributed PAC devices. The desired control behaviour of this system can be described in many different settings. The most common of which is to use a central configuration for controlling the behaviour but for a complex system a hierarchical modular design is more suitable [4]. The following section discusses the central control, and a distributed design approach in the context of IEC 61499 standard.

3. Control application architecture

The control software of the demonstrator is implemented in IEC 61499. It is divided into the sections corresponding to the physical parts of the device. Fig. 2 shows the function block distributed across the six devices according to the functionality. Also, Fig. 3-5 present the Execution Control Charts (ECC) for the conveyor, jack and gripper to control the respective hardware sections.

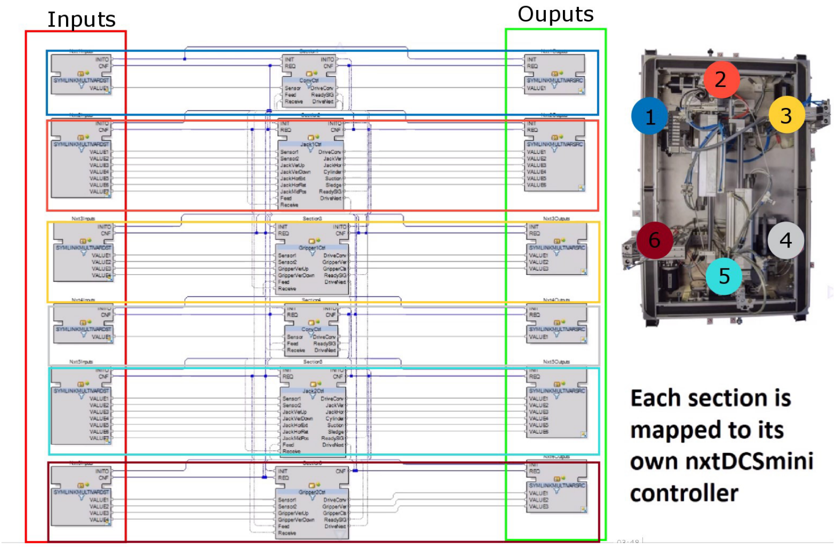

Fig.2. Modular software architecture of the EnAS demonstrator.

Design is modular where a single function block implements the functionality of the section corresponding to the related hardware section. The blocks functionality is implemented with ECC state machine that realized the actions needed for each state and takes care of transiting from one state into another when certain conditions are true. Each of these blocks took the corresponding inputs of the section and execution permissions as inputs and delivered corresponding outputs of the section as well as execution permissions for other sections. The sections are networked with each other by connecting their ReadySIG output defining whether the section is ready to take a new pallet to the feed and receive inputs of neighbouring sections in order to create a structure where the sections request and feed pallets from the previous section to the next one.

Software of the original system was implemented using FBDK and 4DIAC software tools. The automation logic of some components was reused from the legacy applications. The migration path to nxtSTUDIO was very straightforward thanks to the common standard based XML representation of function blocks in IEC 61499.

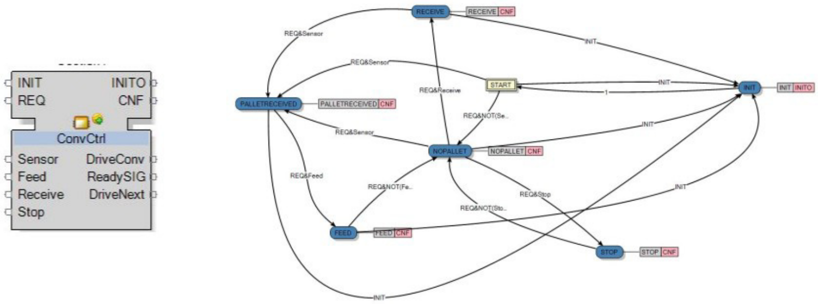

Fig.3. ECC of the conveyor control.

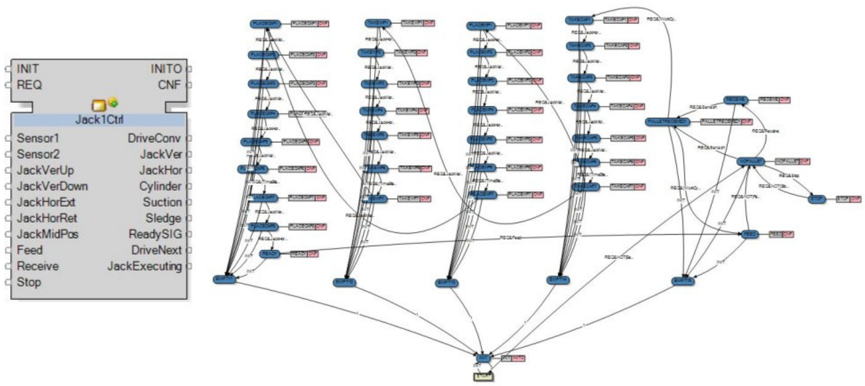

Fig.4. ECC of the Jack control.

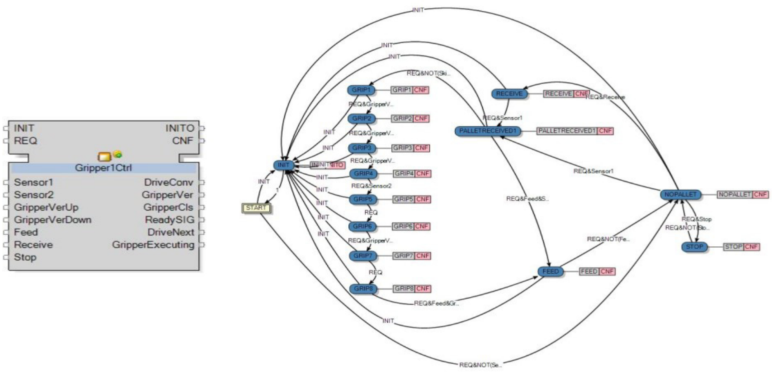

Fig.5. ECC of the gripper control.

A human-machine interface (HMI) for the control system is shown in Fig 6. It should be noted that the HMI was developed using the CAT + Canvas mechanism of nxtSTUDIO, which allows creation of multiple HMI screens for the distributed control system without using external mechanisms such as OPC servers. The HMI and the control nodes communicate in peer to peer way.

In the distributed control architecture, all the system sections communicate with the adjacent sections making the system more flexible compared to the centralized control system, and easy to reconfigure. It also facilitates software update on the fly for specific part of the system. Each of the section controller blocks and all the other function blocks related to the same section runs on one PAC and therefore easily updated by the click of the update button. Extending the system application does not require any drastic modifications to the code, as only a controller, input and output blocks for a new section and a small degree of function blocks reconnection is needed.

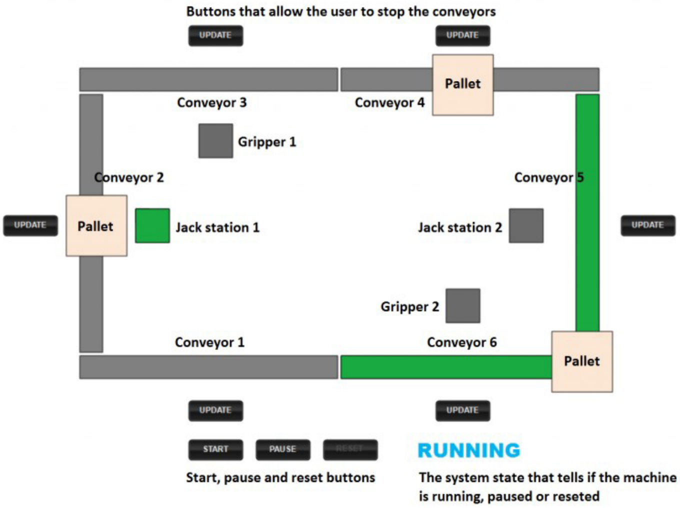

Fig.6. HMI interface for updates and user input.

4. Deployment

4.1Wired

The developed software application was tested in three hardware configurations: centralised, distributed wired, and distributed wireless.

A central control solution runs the control logic on a single PAC. One nxtDCSmini has only 8 input and 8 output pins but we needed 27 inputs and 23 outputs for the whole system to run. For a central control solution, we decided to map all the function blocks responsible for control on a single nxtDCSmini and use the other PACs solely for connecting the remaining inputs and outputs to the program. This way the central control solution was tested successfully. The main issues arising during the central control phase related to getting desired outcomes with the nxtSTUDIO programming environment, getting all parts functioning based on I/O mappings as well as iteratively configuring and debugging the hardware setup for correct timings at photo sensors.

After successfully testing the centralised control system, the application control is distributed using the IEC 61499 standard and wired connectivity with Ethernet cables connecting the PACs. The application can be deployed to a different set of hardware configurations. The process of converting an IEC 61499 centralized application to a distributed application is explained in [6]. Firstly, all the inputs and outputs of the system to six PACs based on the physical structure. Thus, the control system has six controllers, one for each section of the EnAS Demonstrator.

With the distributed control architecture, the system also supports online software update feature mentioned earlier. The controllers controlling individual sections can easily be given a signal to stop all its operations whenever it is ready to start updating ceasing its currently ongoing operations. This is a notable advantage because on-the-fly system update enables the whole system to be updated without the update process even affecting the operation of the system with an optimized update schedule. The idea demonstrated the possibility to stop individual sections and update with currently running assembly process.

4.2 Wireless

The six nxtDCSmini10 PACs communicate natively with each other over Ethernet. Traditionally the Ethernet connection is realized with physical Ethernet cables. However, the system is migrated from this traditional approach into a wireless one due to its greater degree of flexibility. We added a wireless feature to the demonstrator by building a setup where each of the PACs communicates with the help of a wireless dongle Fig. 7. The wireless dongles act as a Wi-Fi bridges connecting these PACs to a secured local network managed by a wireless access point. Software configuration and device mapping are not modified for the wireless solution, which validates the concept of an easy scalability of IEC 61499 distributed system to a wireless solution.

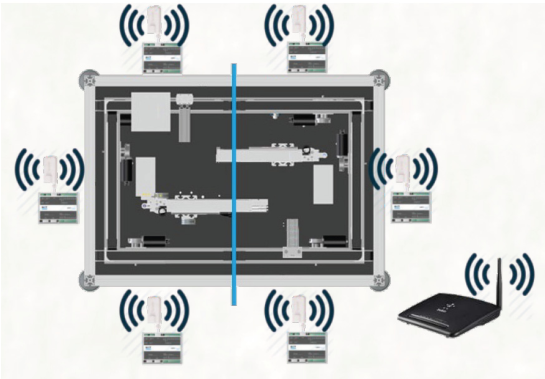

Fig 7. Wirelessly connected network of PACs.

5. Conclusions

This study explored the scenario of an automated system upgrade, both mechanical and electronics, which required substantial software modifications. The latter, however, was facilitated by the software compliance with the IEC 61499 standard.

The developed configuration possesses outstanding flexibility characteristics allowing deployment of the same software to centralized and distributed configurations with wired and wireless communications. The adaptability of IEC 61499 standard has allowed very easy transition from a central design to a distributed design for the wired, and wireless solutions through code reuse. The comparison between wired and wireless solution showed that in the factory-like environment there was no visible difference in performance. However, the solution requires further investigation on how the PAC technology will develop and distributed when the wireless devices grow in number. Also, one to one mapping of the FB from the control to the device function has been demonstrated. Furthermore, a simulation model was created which can be connected to the control software for behavioral simulations.

In the future wireless devices, clock synchronization scheme as in [5] can be added to the wireless solution. Further improvement can be done also by optimize sending the events between controllers so that the controllers communicate with each other using different events that are not sent always when a controller reaches new state i.e., the purpose is to get rid of all the unnecessary communication. From the business perspective, utilizing distributed and wireless solution with online and dynamic updates makes it possible to considerably decrease the traditional downtime costs in manufacturing factories and larger complex systems. By using the developed online update solution, active production lines can be updated on-the-fly without shutting down the factory operation.

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