A Digital Twin Demonstrator for Research and Teaching in Universities

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Abstract. The importance of digitization in production and training was recognized and has found its way into many companies nowadays. Technologies such as IoT, rapid prototyping, and digital twins can be used to advantage in these fields. In order to show the numerous possibilities of such technologies, a digital twin demonstrator was built and extended to include virtual and augmented reality for control, data exchange, and data visualization. This demonstrator can be used for R&D topics as well as for teaching undergraduates and co-workers. A very flexible system configuration enables to adapt to many different tasks and can be easily reproduced. Future topics will be to exchange components, e.g., Python instead of MATLAB, alternatives to MQTT, etc., to increase the flexibility and check for the latency of the data connection via the internet. Research extended from the demonstrator is also presented in the paper to show how to use Node-RED installed Raspberry Pi to build an industrial IoT in a factory.

Keywords: Internet of Things · Rapid prototyping · Digital twin · Virtual reality · Augmented reality

1 System Configuration Digital Twin Demonstrator

As published in [1] a demonstrator was built in order to show the important characteristics of a digital twin on a simple system, which can be reproduced easily and cheaply. The physical system is a ducted fan driven by a DC motor with rotational speed, current, and temperature sensors connected to an Arduino, as shown in Fig. 1. Furthermore, a Programming Logic Controller (PLC) or microcomputer, e.g., a Raspberry Pi, could be used instead of an Arduino microcontroller. The digital twin is a virtual replica of the demonstrator incorporating data acquisition and processing, system modeling and control, condition monitoring, and a remaining useful life model, all built in MATLAB®. Digital twins can be used advantageously along the product development process in the design, build and operate phase as well as in production processes [2].

In this work, an extension of the digital-twin demonstrator using VR and AR technologies for human-machine-interaction and data visualization is presented. As shown

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in Fig. 1, a CAD model of the real object is used within the AR-software tool Vuforia studio® to add effects animations (GIFs) for the rotational speed (RPM), current (Amp), and temperature (Temp) of the motor in real-time.

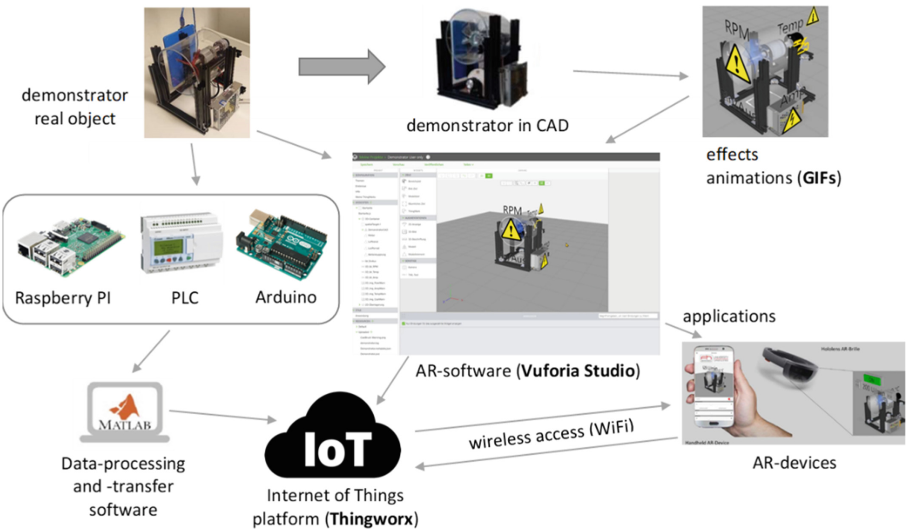

Fig. 1. Digital twin demonstrator - system configuration

The IoT platform Thingworx® is used as a data interface and IoT hub for the connected devices and the data-processing software.

2 Teaching Aspect by Using the Demonstrator

The demonstrator can be used for R&D as a very flexible system in retrofitting existing machines and production facilities, for small and medium enterprises (SMEs) who may not be the experts in this field, and for teaching low-skilled workers on new production systems as well.

Using the demonstrator for teaching students can be conducted in many different ways. What students learn from the simulation can be implemented in the real system for verification. In the meantime, the Internet of Things can be introduced through single-board computers such as Arduino or Raspberry Pi. For the Internet of Things software, in addition to using commercial Thingworx, we can also introduce students Node-RED, an open-source tool contributed by IBM. Node-Red can be installed on Raspberry Pi so that the Raspberry Pi becomes a lightweight IoT gateway. Students can learn how to communicate with OPC UA-based machine controllers or Modbus PLCs using Node-RED installed Raspberry Pi.

3 Research Aspect Extended from the Demonstrator

Suppose a factory wants to connect all the machines to a network to monitor the status of each machine. In that case, it most likely needs to rely on a commercial SCADA system. The small and medium-sized enterprises (SMEs) may not like this idea because it will increase the operation cost. The CNC controller manufacturers offer solutions for connecting to their devices. Annad et al. [3] used the Simatic Manager provided by Siemens to access the data of the Sinumerik 828D controller. Guo et al. [4] used VS2013 and the FOCAS library provided by FANUC to develop codes to collect the information on FANUC CNC machines. However, developing codes requires skilled programmers, which SMEs usually do not have.

Node-RED, an open-source software, has become a suitable development software to integrate machines in the factories of SMEs. Node-RED has built-in nodes of various communication protocols, which can save complicated programming. As a result, it has been used to build an industrial IoT architecture. For example, Newman et al. [5] selected the corresponding nodes of Node-RED to establish connections with different devices according to their communication protocols.

The objective of this extended research was to propose a technique to build an industrial IoT architecture in a factory based on Node-RED. The industrial IoT was used for communicating between the CNC controllers of Siemens and FANUC and the sensors through the PLC of Delta. We used Raspberry Pi 4 Model Bas the IoT gateway. The IoT system can allow us to monitor the controllers and sensors and present information such as the machining parameters and overall equipment efficiency (OEE) of each machine in a dashboard. In addition to accessing the data from the controllers and sensors, we also can upload the data and commands to the controllers to realize two-way communication.

The vertical five-axis milling CNC machine to be connected in this study was made by Dongtai Seiki, and its model number was CT-350. The controller installed on the machine is Sinumerik 840D sl, equipped with an OPC UA server inside. The data can be exchanged with the OPC UA communication protocol. This study will also connect the PLC device AH500 made by Delta. AH500 has RJ45 and RS485 communication ports and supports Modbus TCP communication protocol.

Node-RED is a powerful tool for building an IoT program. Its focus is to simplify the complexity of developing the program using a visual programming method, allowing developers to connect pre-defined nodes to build programs. Users can drag and drop nodes to create a flow. The program usually starts from the leftmost node of the flow and runs through the entire process to the right. Node-RED has nodes providing various communication protocols, such as OPC UA, Modbus, MQTT, etc.

In this study, the function of reading and writing Siemens controller information is established based on the OPC UA communication protocol. To establish the read/write function in the controller, we need to know which parameters the controller has captured. The parameter list can be found in the Siemens NC Variable Parameter Manual.

The structure of this research is illustrated in Fig. 2. We used communication protocols such as OPC UA and Modbus to connect with the equipment. The connected devices include a Siemens controller and a FANUC controller. In addition, the sensors and actuators without connection capability were connected to the IoT architecture using Delta PLC. The system uses Raspberry Pi as the IoT gateway and Node-RED software to integrate the data transmission of devices with different communication protocols, thereby completing applications such as data visualization, machine monitoring, and remote control of the machines.

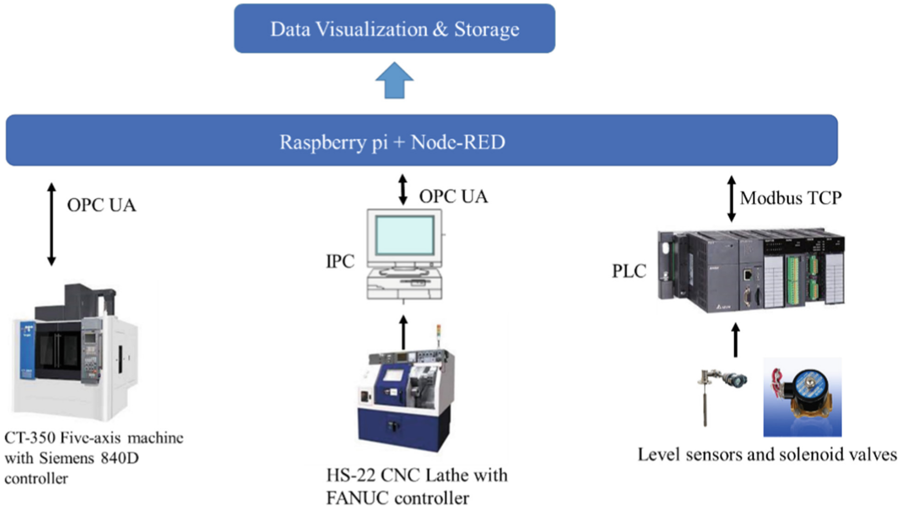

Fig. 2. The schematic illustrates the communication protocols and the connection for establishing the industrial IoT in the research.

The network connection architecture of this study is shown in Fig. 3. The five-axis milling machine, PLC and Raspberry Pi are connected to the network switch, while the lathe needs to be connected through an industrial PC connected to the switch. The Raspberry Pi system server controls all devices via the Ethernet connection.

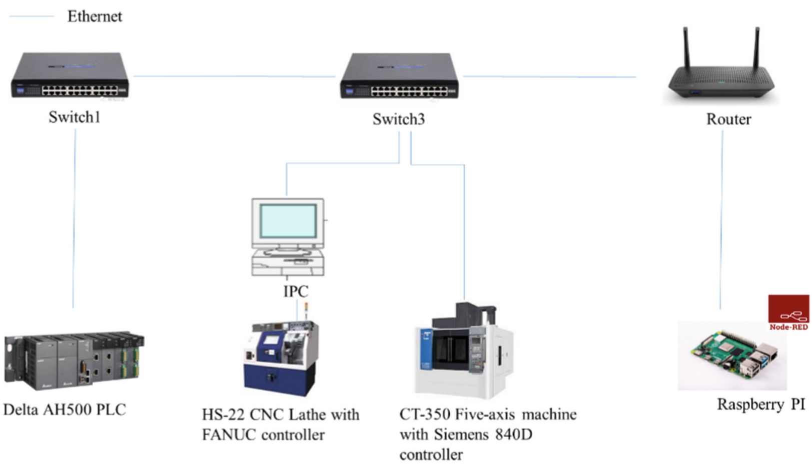

Fig. 3. The network connection of the industrial IoT in this research.

We would like to monitor the status of the connected machines remotely, so a dashboard for the machines was established. It includes machining data and other information. The machining data includes axis locations, tool information, feed rate, machining time, number of workpieces machined, program status, etc. We also developed the function so the operator can remotely upload the NC program, select the NC program to be executed, and start the operation.

This study uses the OPC UA protocol for communication with the CNC milling machine. The OPC UA has a server that can provide information to the client. The server installed in the CNC controller contains the information of the CNC machine in its nodes, and the NodeId of the node is required to know the data.

The machine data monitoring function is mainly established through the OPC UA client node in Node-RED. An example of the Node-RED program is shown in Fig. 4. The data flow is from left to right. There are three nodes in this program. The inject node is used to set up the NodeId for the OPC UA node to be read. Then the client node obtains the information from the server based on the received NodeId from the inject node. Finally, the dashboard node displays the information on the webpage.

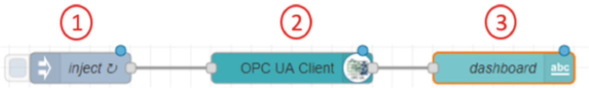

Fig. 4. The Node-RED flow for accessing the data from the controller via OPC UA and displaying the data in a dashboard. (1): inject node; (2): node of OPC UA client; (3): dashboard node.

We also use Node-RED to connect Delta's AH500 PLC, a gateway for level sensors and solenoid valves. The level sensor was installed on the cutting fluid storage tank of the CNC machines, and the solenoid valve was installed on the water pipeline. When the cutting fluid is consumed to the set level, the solenoid valve will automatically open and make up enough cutting fluid. In this study, the PLC is connected to the Internet of Things architecture to monitor the fluid level. The communication protocol supported by the AH500 PLC is Modbus TCP. We used the Modbustcp node in Node-RED to establish the function of reading and writing PLC points. After the data is retrieved from the Modbustcp node, the data is processed separately. The Node-RED program for developing the function of the PLC AH500 is illustrated in Fig. 5.

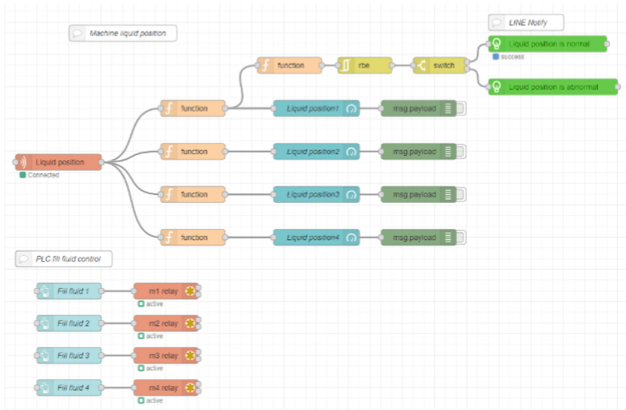

Fig. 5. The Node-RED program for developing the functions of the PLC AH500.

This research integrates different devices through the Raspberry Pi and Node-RED, captures the data, and makes it into a dashboard to display on the web page. The OPC UA Client node on Node-RED exchanges data with the machine controller to complete the real-time machine parameter monitoring, machine usage status, and remote operation functions. The dashboard displays the information about the machine, as shown in Fig. 6 [6]:

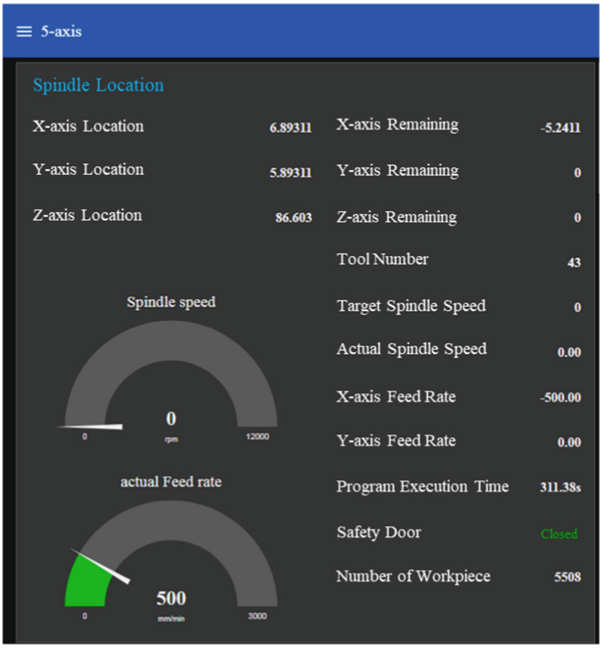

Fig. 6. The dashboard, created by using Node-RED, displays the machine parameters, such as the position of each axis, the spindle speed and the feed rate, etc.

(1) Machine parameters: This dashboard displays the position of each axis and the remaining distance from the target point. It also displays the machining information, including the target spindle speed, the actual spindle speed, the feed rate, the tool number, and the machining time.
(2) Program status: This dashboard displays the file name of the current NC program, the execution status, and the executing G-code. This dashboard also provides the remote operation function. The upload file name of the NC program can be input so that the file will be sent to the CNC machine. The three buttons in the middle can control the program execution. When the file upload is completed, pressing the start button can start the program execution. If an abnormality occurs, pressing the stop button can stop the machine. Pressing the reset button can allow the users to reselect the program to be executed.

4 Conclusive Remarks

In this paper, we described how to build a digital-twin demonstrator, which can be used as a teaching tool in universities. We also showed how to build an industrial IoT system integrating machines of different communication formats, using a low-cost Raspberry Pi as the IoT gateway and open-source Node-RED as the development software. Through the nodes provided by Node-RED, different machine controllers and sensors with various communication protocols were connected, and sensors without connection capability were connected using a PLC. All the captured information can be displayed through a dashboard on a webpage for easy access.

References

1. Jungwirth, M., Hehenberger, P., Merschak, S., Lee, W.C., Liao, C.Y.: Influence of digitization in mechatronics education programmes: a case study between Taiwan and Austria. In: 21st International Conference on Research and Education in Mechatronics, REM 2020, p. 7. Institute of Electrical and Electronics Engineers Inc. (2020)
2. Fuller, A., Fan, Z., Day, C., Barlow, C.: Digital twin: enabling technologies, challenges and open research. IEEE Access **8**, 108952–108971 (2020)
3. Anand, P., Philip, V.L., Eswaran, P.: Cost effective digitalization solution for Sinumerik CNC system to increase the transparency and utilization of the machine. Int. J. Recent Technol. Eng. **8**(2), 6–13 (2019)
4. Guo, Y., Sun, Y., Wu, K.: Research and development of monitoring system and data monitoring system and data acquisition of CNC machine tool in intelligent manufacturing. Int. J. Adv. Rob. Syst. **17**(2), 1–12 (2020)
5. Newman, D., Parto, M., Saleeby, K., Kurfess, T., Dugenske, A.: Development of a digital architecture for distributed CNC machine health monitoring. Smart Sustain. Manuf. Syst. **3**(2), 68–82 (2019)
6. Zeng, Y. J.: Design and Implementation of IIoT Using Node-RED. Master thesis, National Taiwan University of Science and Technology, Taipei, Taiwan (2022)