DESIGN DIGITAL TWIN FOR AUTOMATIC FEEDING MODEL

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ABSTRACT

With the explosion of the Industrial Revolution 4.0, a series of core technologies are also researched and developed, in which Digital Twin (DT) is a hot trend research recently. The Digital Twin of a system fully describes the state of the execution instance in real-time through the sensors (IoT). In addition, the technology DT allows for a feedback interaction between the real version and its virtual, making it more accessible to the user and more precisely defined controls the real version. Modeling system automation is an entry-level and basic system of the automatic production systems. This article describes the process of DT implementation for the automatic feeding model. With the data obtained from the Digital Twin, this paper demonstrates some research results on working status of the model.

Keywords: *Digital Twin, automatic feeding system, product lifecycle, PLM.*

TÓM TẮT

Cùng với sự bùng nổ của Cách mạng công nghiệp 4.0, một loạt các công nghệ lõi cũng được nghiên cứu và phát triển, trong đó công nghệ bản sao số (Digital Twin) là một công nghệ nổi bật thời gian gần đây. Bản sao số của một hệ thống mô tả đầy đủ trạng thái của phiên bản thực theo thời gian thực thông qua các cảm biến. Bên cạnh đó, công nghệ bản sao số cho phép tương tác qua lại giữa phiên bản thực và bản sao của nó, khiến cho người dùng có thể hiểu rõ hơn và điều khiển được chính xác hơn phiên bản thực. Mô hình hệ thống tự động hóa cấp phôi là một hệ thống đầu vào và cơ bản của hệ thống tự động hóa sản xuất. Bài báo mô tả cách tiến hành thiết lập mô hình bản sao số cho mô hình tự động hóa cấp phôi. Với các dữ liệu thu được từ bản sao số, bài báo đưa ra một số kết quả nghiên cứu, phân tích trạng thái hoạt động của mô hình.

Từ khóa: *Digital Twin, bản sao số, hệ thống tự động cấp phôi, vòng đời sản phẩm, PLM.*

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Received: 25/6/2021
Revised: 20/9/2021
Accepted: 15/11/2021

1. INTRODUCTION

Along with the development of new generation information technology such as cloud computing, Internet of things (IoT), big data (Big Data) and artificial intelligence (AI), the role of virtual space is becoming more and more important, and real-virtual interaction is needed more than ever. Therefore, the seamless integration and combination between the two objects will be an inevitable trend, which will create a new potential to improve the current situation and technology in the fields of design, manufacturing, service, etc.

In 2003, The conceptual version of Digital Twin was firstly presented by Grieves [2] in his lecture on PLM. It can be proposed that virtual models of physical objects are created in a digital way to simulate their behaviors in real-world environments [3]. The Digital Twin was proposed and adopted by NASA for monitoring and optimization on safety and reliability optimizations of spacecraft. Therefore, the DT is comprised of three components, which are the physical systems, the virtual models and the connected data between the two worlds. The DT reflects two-way dynamic mapping of physical objects and virtual models. The figure 1 describes the Digital Twin paradigm and the functions of each part in physical and digital models [4].

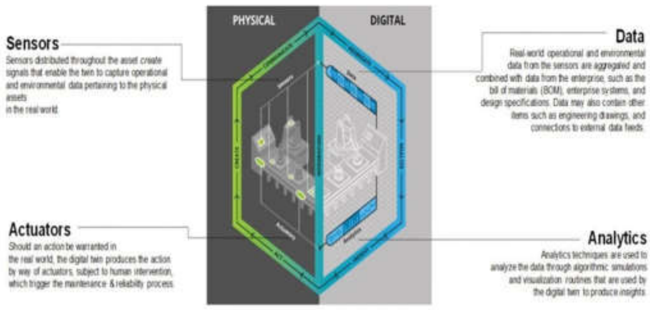


Figure 1. The paradigm of Digital Twin

The sensors and actuators of physical systems create and send the signals to the digital models. In the opposite direction, the digital models collect the data received from physical systems; store and analyze the data to predict the "behavior" of the physical systems. In comparison with other simulation models, the DT fully mapping with the physical systems in real-time. It means that the real systems can react to the control signals from digital models and the models can change their state due to the status of real systems [5].

Despite of the fact that the DT was first born in the aerospace field and only recently has been adopted also in manufacturing contexts, which is used in industrial environments and in governmental research initiatives; however, scientific literature that describes the contextualization of the concept in the manufacturing domain is still at its infancy [7]. The implementations of DT for manufacturing can be described as follows: promotion in product design, manufacturing, and service [8], individualized designing of the production line [9], integrated into the machine tool manufacturing processes [10], embedded on the device or available on cloud or edge computer, a loop between the real world and the digital world and back to the real thing is possible [11],… Most of the mentioned papers primarily reviewed the advantages of DT and implemented DT as the concept for manufacturing systems. In 2018, researchers from DiK research lab made an approach to demonstrate DT concept on a bending beam to collect the properties, condition and behavior data [14]. The experiment was developed to prove the concept of the digital twin though the setup still had limitations [13-16].

This paper aim to implement DT for the automatic feeding model, which is subsystem of the automatic manufacturing system. The outline for the paper is organized as follows. Section 2 describes the architecture and design of the automatic feeding model. Digital twin model is presented in section 3. Section 4 give the experiments on working conditions and discussion to verify the proposed model. Section 5 makes the conclusion.

2. AUTOMATIC FEEDING MODEL

The automatic feeding system selects, guides and positions the workpieces exactly to specified orientation and enable their subsequent handling and assembly. In this situation, the workpieces is stored in the workpiece troughs, then transfered to next position of the production line by the robot arm. In the laboratory, the automatic feeding system is contructed as a single compacted module, which can be operated itself or can cooperated with other module to make the assembly line or production line. The automatic feeding model is designed and used as the physical object at the laboratory of Department of Mechanical Technology, Le Quy Don Technical University.

2.1. System structure

The feeding model has 4 main components:

- three workpiece troughs, which is used to store three type of workpieces.
- pneumatic cylinders to push the workpiece to the position, where robot arm can grip and transfer.
- clamping arm with 3 degree of freedom transferring workpiece to next block.
- the control unit using Omron PLC to manage all the operations of the model.

a) Workpiece and trough

There are three types of workpiece, which are made of aluminum, polyurethane resin. Workpiece is designed to fit with the bowl feeder, described in the Figure 3. The minimum workpiece in the trough is 10.

b) Pneumatic cylinders

Workpiece push mechanism runs with pneumatic cylinders, which can change speed by the throttle. The air pressure operates at 2bar on the distance of 60mm.

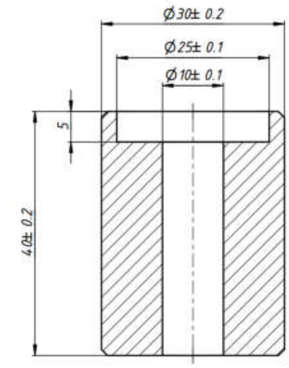


Figure 2. The automatic feeding model Figure 3. Workpiece

c) Clamping arm

Figure 4 show the 3D design model of the clamping arm.

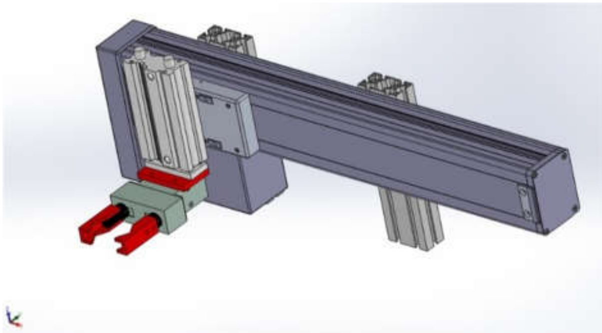


Figure 4. 3D model of clamping arm

The workpiece, after moving to the end of the stroke of the workpiece trough, will be pushed by the cylinder to the position of the clamping arm. The clamping arm has the function of clamping the workpiece and bringing the workpiece according to the transport-oriented mechanism to the position of the next function block.

d) Control unit

In order to control the automation system of the workpiece feeding system, it is necessary to control many physical quantities simultaneously. Therefore, it is impossible to use the analog or discontinuous control circuit, but the PLC system is needed. The PLC used in the system is Omron CP1H with 24 built-in inputs, 16 built-in output, RS485 port communication connecting to PC through Ethernet [17].

To collect information from the physical model, sensors were installed at operating positions. There are three type of sensors: magnetic, optical. The PLC collects all the signal from sensors and send the command signal back to the physical model.

Figure 5 describes the process implementation of DT for the automatic feeding model. Physical object is controlled by the PLC control unit, sends signal detected by the sensors to the PLC control unit and gets back the command signal. The monitoring software, which is developed in Matlab, interacts with PLC control to view the system signal and can interfere by the user command. DT is created and connected directly to the monitoring software. By viewing DT, user not only can operate the working status in real time, but only can predict the working problems of the system in the future.

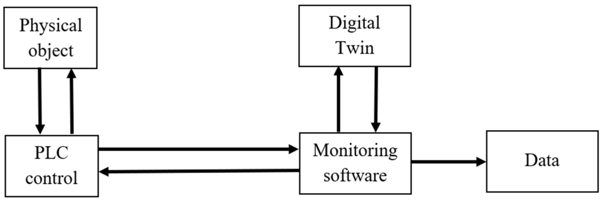


Figure 5. Process implementation of DT

2.2. Operating procedure

The purpose of automatic feeding system is to transfer the workpieces from trough to position of next block, the operating procedure is described in the Figure 6 with five steps.

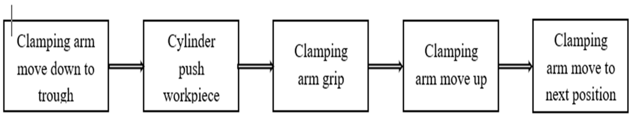


Figure 6. The operating procedure of the feeding model

• Firstly, when automatic feeding model is activated, the clamping arm returns to trough, which is noticed by the sensors, and move down;

• Next, the pneumatic cylinder pushes the workpiece to the specified position for transferring;

• The clamping arm grips to hold the workpiece;

• Then, the clamping arm moves up with the workpiece;

• Finally, the clamping arm moves along the guide bar to transfer position with next block.

These five steps also are considered as the basis for the analyzing stage to define the transferring cycle, i.e. the cycle begins with the returning of clamping arm to the trough and ends with the moving of clamping arm to the transfer position.

3. DIGITAL TWIN MODEL

3.1. Simulation

This section will explain the implementation of the automatic feeding model in the virtual environment. Due to the structure and the operation purpose, the simulation model was built based on the following 16 status parameters: status of the three troughs (3), status of cylinders (3), position of clamping arm (3), status of clamping arm (4), status of the system (3). The PLC control unit send these parameter, to the monitoring software to simulate the Digital Twin. The value of parameters are set 1 if sensor is ON and 0 - OFF. For example, status parameter of the system when pneumatic cylinder pushes the workpiece is: 110 100 100 0001 101.

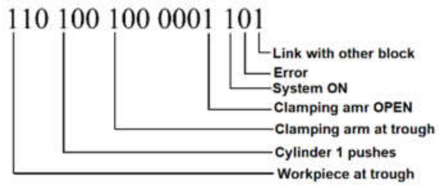
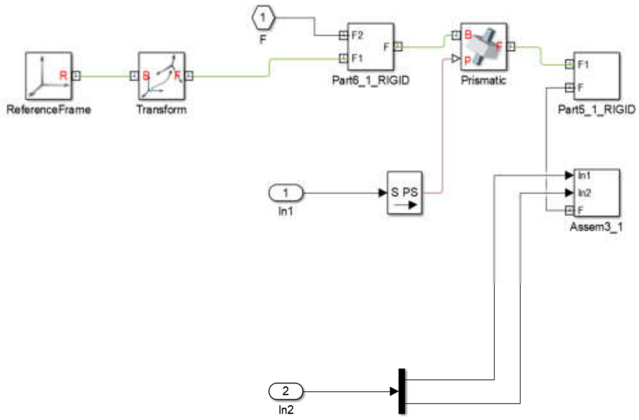
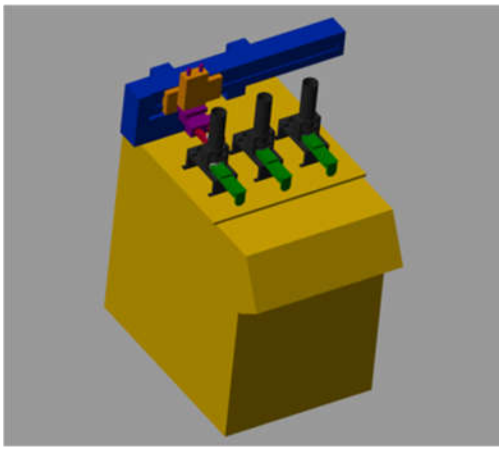


Figure 7. Status parameter of the system

The digital model was simulated in Matlab with plug-in Simscape Multibody Link. The model comprises of 3 main block of: pneumatic cylinder (Fig. 8a), clamping arm and guide bar. Figure 8b shows the model simulation.



a)



b)

Figure 8. Simulation of the system

a) control block of pneumatic cylinder; b) model simulation

3.2. Data monitoring

The main function of the Digital Twin technology is to store and analyze data. Hence, the monitoring program and the PLC unit need to make communication, in the form question-answer, between them all the time the system works. Because the PLC can scan all the input in a very short time (10ms) in comparison to each operation cycle (about 5 - 10s), so the monitoring program set the question interval of 0.5s. This interval ensures that all the status of the automatic system remain on the monitoring screen. The algorithm of collecting data is performed in the following Figure 9.

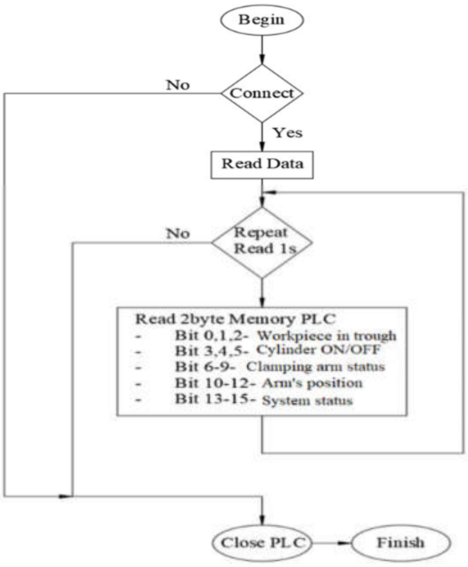


Figure 9. Collecting data algorithm

The status of automatic feeding model is displayed in the monitoring program, as shown in the Figure 10. The monitoring program works at two mode: online and offline. Online mode shows the data of the system in real time. Offline mode can describes all the saved data in the past. The latency between question from monitoring program and answer from PLC is low at about 46 to 170 miliseconds, not affected to control the physical system.

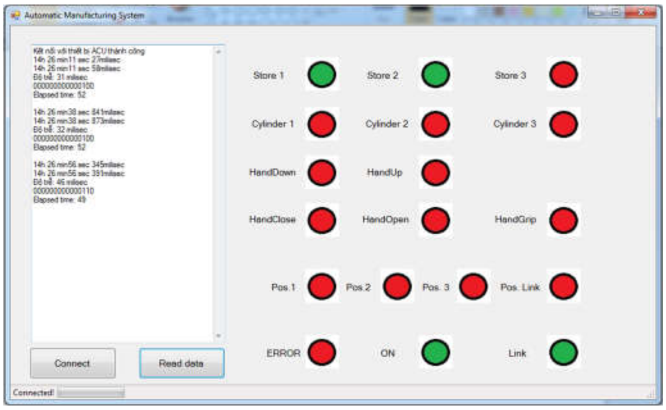


Figure 10. Monitoring program

In the other hand, the monitoring program can interact back to the physical system by sending the command signal to PLC to change the operating parameters, such as transfer velocity and accelerity of clamping arm, return velocity and accelerity of clamping arm, workpiece priority. These parameters have important effect on the productivity of the system.

Figure 11 shows the data is collected by the monitoring program. The data saved not only the status but also the data and time of working.

Analyzing the data, user can visualize the working process of the system, such as the total count of each workpiece type, total or average time transfer, average waiting time of each workpiece. Especially, user can view the error on the working period time, which is important parameter to enhance the productivity of the system.

AutoRun	Store 1	Store 2	Store 3	Cylinder 1	Cylinder 2	Cylinder 3	HandDow	HandUp	HandClos	HandOpe	HandGrip	Position 1	Position 2	Position 3	Hour	Min	Sec	Day
1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	8	35	41	4/29/2021
1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	8	35	41	4/29/2021
1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	8	35	42	4/29/2021
1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	8	35	42	4/29/2021
1	1	0	0	0	0	0	0	0	1	0	1	0	0	0	8	35	43	4/29/2021
1	1	0	0	0	0	0	0	1	1	0	1	0	0	0	8	35	43	4/29/2021
1	1	0	0	0	0	0	0	1	1	0	1	0	0	0	8	35	44	4/29/2021
1	1	0	0	0	0	0	0	0	1	0	1	0	0	0	8	35	44	4/29/2021
1	1	0	0	0	0	0	0	0	1	0	1	0	0	0	8	35	45	4/29/2021
1	1	0	0	0	0	0	0	0	1	0	1	0	0	0	8	35	45	4/29/2021
1	1	0	0	0	0	0	0	0	1	0	1	0	0	0	8	35	46	4/29/2021
1	1	0	0	0	0	0	0	0	1	0	1	0	0	0	8	35	46	4/29/2021
1	1	0	0	0	0	0	1	0	0	1	0	0	0	0	8	35	47	4/29/2021
1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	8	35	47	4/29/2021
1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	8	35	48	4/29/2021
1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	8	35	48	4/29/2021
1	1	0	1	0	0	0	0	1	0	1	0	1	0	0	8	35	49	4/29/2021
1	0	0	1	0	0	0	0	1	0	1	0	1	0	0	8	35	49	4/29/2021
1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	8	35	50	4/29/2021
1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	8	35	50	4/29/2021
1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	8	35	51	4/29/2021
1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	8	35	51	4/29/2021
1	1	0	1	0	0	0	1	0	0	1	1	0	0	0	8	35	52	4/29/2021

Figure 11. Saved working data

4. EXPERIMENTAL DETAILS and discussion

An experiment was recorded for a full shift time on the automatic feeding model. The number and the priority of the workpieces are set up randomly. Figure 12 shows the total count of each workpiece of an experiment. It is clearly to view each type of workpiece. In this data, workpiece type 1 was transfered 35 times, workpiece 2 - 29 times and workpiece 3 - 42 times.

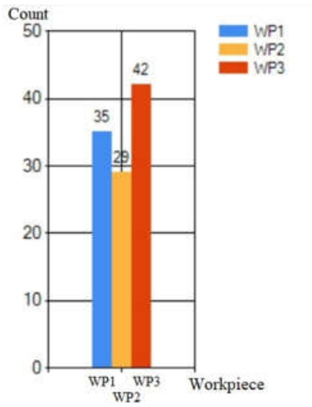


Figure 12. Total count of workpiece

Figure 13 shows the timestamp of all the workpieces. The priority and the time of each cycle time are shown on the figure. It is observed that the priority for the workpiece is the third trough firstly, then the second and the first trough at the last queue.

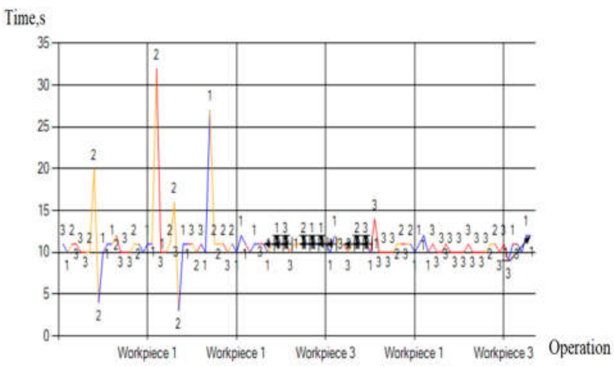


Figure 13. Timestamp of each cycle

The most important thing that the digital twin gives to observer is the monitoring program visually shows the error of operation. As shown in the figure 12, there are three counted errors appearing in the working shift, as follows workpiece 1 - 1 time, workpiece 2 - 2 times.

Another parameter which obtained from the data is the total waiting time of workpiece. Figure 13 shows the waiting time of each workpiece, i.e. the first workpiece type waits for 883 seconds totally, the second type - 408 seconds and the third type - 338 seconds. It means that the bigger waiting time is, the more number of workpiece waits at the trough. Obviously, the operating process is not optimized and it could decrease the productivity of the system. Optimizing this parameter is also a problem to be solved of each production line.

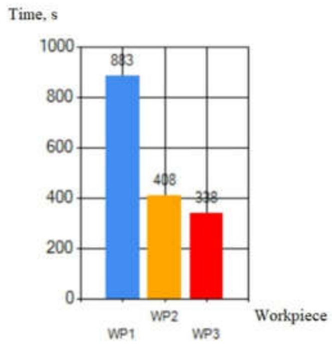


Figure 13. Waiting time of workpiece

5. CONCLUSIONS

This work addressed an approach to realize the Digital Twin of an automatic feeding model, a part of an automatic production system. The author made the first steps to connect the digital models to physical system through the Ethernet connection. The conclusions are listed as:

1) The physical system connects digital models in real time with low latency (46 - 170 milliseconds). The physical system can work as the script built by the author, the digital models reflects exactly the way the physical system operates.

2) Collect and save working data to analyze the working shift. The status of the system was shown visually by the following parameters: total count workpiece, timestamp, waiting time.

3) The data can be used to predict the status of the system in the future to make maintenance decision, error detection. This is also the perspective research for the Digital Twin problems.

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