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USING A DIGITAL TWIN FOR DIAGNOSTICS OF TECHNICAL SYSTEMS

Octavian Narcis VOLINTIRU, Mihail - Vlad VASILESCU, Ionut Cristian Scurtu, A. I. Epikhin M.A. Modina

The article discusses the features of the development and application of a digital twin for the diagnostics of technical systems. Special attention is paid to the choice of the most appropriate type of digital twin. Also, in the process of research, a functional diagram of the interaction of the digital twin and the process under study was built. In addition, an algorithm for the development and use of a digital twin for diagnosing the technical condition of an industrial robot is proposed.

Key words: robot, diagnostics, digital twin, algorithm.

ИСПОЛЬЗОВАНИЕ ЦИФРОВОГО ДВОЙНИКА ДЛЯ ДИАГНОСТИКИ ТЕХНИЧЕСКИХ СИСТЕМ

Octavian Narcis VOLINTIRU ,
Mihail - Vlad VASILESCU,
Ionut Cristian Scurtu,
А.И. Епихин, кандидат технических наук, доцент
М.А. Модина, кандидат технических наук, доцент

В статье рассмотрены особенности разработки и применения цифрового двойника для диагностики технических систем. Отдельное внимание уделено выбору наиболее подходящего типа цифрового двойника. Также в процессе исследования построена функциональная схема взаимодействия цифрового двойника и исследуемого технологического процесса. Кроме того, предложен алгоритм разработки и применения цифрового двойника для диагностики технического состояния промышленного робота.

Ключевые слова: робот, диагностика, цифровой двойник, алгоритм.

To date, the automation of production processes and technological systems has moved far ahead. In the context of the Fourth Industrial Revolution, a large modernization is being carried out, many control and monitoring systems have been developed, a variety of sensors and devices control the operation of equipment and components, and many processes are performed automatically. The information generated by such technological systems is measured in terabytes [1].

Under these conditions, modern engineering science is trying to solve a wide range of diverse problems, such as increasing operational efficiency, reducing unplanned equipment outages, reducing downtime, increasing and improving profitability. Shutting down a particular technology node can mean losing thousands of dollars every minute. Performing regular maintenance helps avoid unplanned downtime, but does not guarantee that equipment will not fail.

The development of any predictive maintenance system for technological systems is based on sensor data that can be used to train a classification and fault detection algorithm. This algorithm is then exported to simulation software such as Simulink ® and then embedded into the control block as code [2]. However, it is not always possible to obtain data from physical equipment in the field with typical failures. In turn, deliberately generating failures under more controlled conditions can be time consuming, costly, and in some cases even impossible.

In this case, targeted measures can only slightly increase the efficiency of diagnostic operations. Obviously, in order to solve the problem, a comprehensive response based on analytical science and advanced digital technologies is fundamentally needed.

It seems that the solution to this problem is the creation of a digital twin of a technological system or specific equipment. This approach will allow engineers to generate all the sensor data needed for a predictive maintenance workflow, including tests with all possible combinations of faults and faults of varying severity.

Thus, the study of the possibilities of using a digital twin to increase the level of performance and reliability of technological systems is an urgent task today, which determines the choice of the topic of this article.

An analysis of modern methods for managing the process of servicing components of various technical systems is contained in the works of such authors as: Valeev A.R., Mastobaev B.N., Akokhova N.V., Zakiryanov R.M., Wang, Yucheng; Tao, Fei; Zhang, Meng; Wang, Lihui.

Features of the introduction and use of digital twins as a modern way of monitoring the technical condition of equipment of various industrial systems, engineering units and assemblies are described by Feoktistov A.G., Kostromin R.O., Sidorov I.A., Gorsky S.A., Basharina O.Yu. ., Hu, Chunhua; Fan, Weicun; Zeng, Elan; Hang, Zhi.

The following researchers paid their attention to the software aspects of the implementation of digital twins, formalization of requirements for computing power: Bublikova A.S., Kabaldin Yu.G., Shatagin D.A., Anosov M.S., Kolchin P.V., Zhang, Chaoyang; Ji, Weixi; Liu, Kuo; Han, Wei.

However, despite the existence of a sufficient number of scientific and technical solutions for the practical implementation of digital twin technology, today there is no systematic approach to solving the problem of creating digital twins, which would take into account all aspects of the application of this technology: from the development of models and processing of multimodal digital twin data to protection information that characterizes the object under study.

In view of the foregoing, the purpose of the article is to consider an integrated approach to the development and application of a digital twin for diagnosing technical systems.

The task of diagnosing technical systems as physical objects using a digital twin includes several important subtasks that are associated with obtaining data about the object of study, preprocessing the data, presenting the data in the form of a certain set (data structure) and subsequent processing [3]. Related tasks that should also be solved within the framework of performing diagnostic procedures are: modeling the state of a technical system, analyzing data that reflect the characteristics of an object and determine the specifics of its operation, as well as describe the external features of the object as a whole and its components.

The digital twin consists of a visual model of the object under study and a behavioral model implemented on the basis of appropriate mathematical calculations and data representation models that provide synchronization between the virtual and real systems at the level of data coming from sensors installed for continuous monitoring of the object under study [4].

To develop a digital twin that will allow diagnostics of technical systems, first of all, it is necessary to choose the type of digital twin used. To select the right digital twin, you should clearly define the scope of the purpose and the benefits that can be obtained from each of them (see Fig. 1).

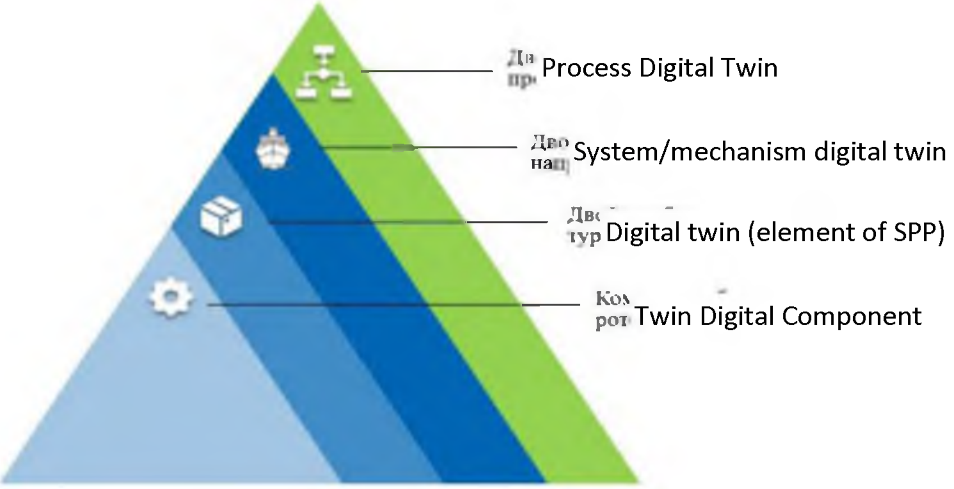

Fig.– 1 Types of digital twins

The biggest difference between the various types of digital twins lies in their scope. Typically, different types of digital twins co-exist in a system or process, the combination of which produces the best effect.

Table 1 provides a more detailed description of the types of digital twins and the scope of their possible application.

To solve the problem of diagnosing technical systems, according to the author, the most appropriate combination of such types of digital twins as a component twin and a process twin. Such a combination will take into account all the necessary aspects of the technological system, including thermal, mechanical, electrical, chemical, hydrodynamic, material, operational, economic, statistical and others.

At the next stage, it is necessary to build a digital twin implementation scheme that meets the initial requirements. Focusing on these conditions, the model should provide control over specific elements and the technical system as a whole, interact with it by obtaining information, storing this information and processing it according to different scenarios [5, 6, 7]. Preliminary testing of the results should also be carried out. According to the result, certain commands can be sent to the element. In other words, an information-measuring system is required that is connected to the control object and receives from it the value of certain parameters. Figure 2 shows a functional diagram of such a model that satisfies the requirements of working with real-time information

Table 1 – Characteristics of different types of digital twins

Type of digital twin	Use case scenario
Component twin, e.g. rotor, blade	Helps field service technicians continuously monitor and offer predictive maintenance, reducing equipment downtime (both planned and unplanned) and enabling predictive maintenance business models for technical systems
Double twin, e.g. turbine, engine	When two or more components work together, they form what is called an asset. Asset twins allow you to study the interaction of these components, creating a lot of performance data that can be processed and then turned into useful information.
Twin of a system/assembly, such as an aircraft	Helps designers, architects and engineers improve future product releases and engineering models to optimize performance and efficiency
Process twin, e.g. manufacturing process	It provides an opportunity to obtain new operational data for production and planning models, which allows formulating strategic conclusions, recommendations, and is also the basis for the development of roadmaps. Also, process twins allow you to determine whether all systems are synchronized in order to work with maximum efficiency, whether delays in one system affect the work of others. Process twins can help identify precise timing patterns that ultimately determine overall efficiency.

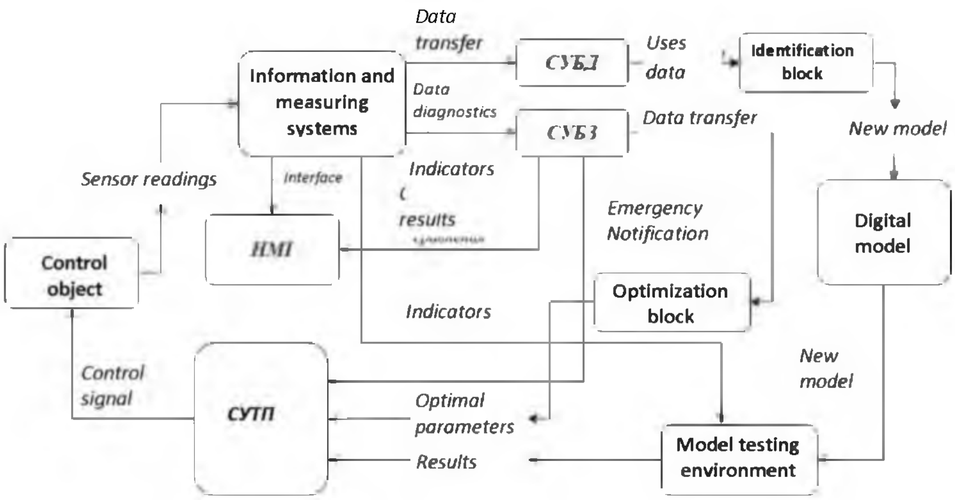

Fig. 2 – Functional diagram of the interaction between the digital twin and the technological system under study

Let us describe in more detail the elements shown in Fig. 2

1. The control object is a technological process, the device whose behavior is monitored. In this case, these can be sensors, the indicators of which will be the input parameters of the digital twin.

2. Information-measuring systems - a set of measuring technical means for obtaining and processing information to the type that is necessary for the operation of the diagnostic system.

3. Human-machine interface (HMI) - providing communication between the operator and the installation. If there is information that needs to be reflected urgently, then it goes specifically through this block. For example, indicators of voltage, temperature, technical fluid pressure, etc.

4. Knowledge base management system (СУБЗ) - works when searching, recording and extracting information from the knowledge base of the system. Knowledge bases contain not only information about the received object, but also inference rules that allow you to build a semantic relationship between incoming and available data.

5. Database management system (СУБД) - provides recording and storage of the necessary information.

6. Identification block - monitoring the current behavior of the technical system.

7. Optimization block - implementation of the scenario for the optimal mode of operation of the technical system.

8. Digital model - builds a model based on the available data, which includes a set of parameters and functions that implement the algorithm of the process of functioning of the simulation object. Thanks to this model, it is possible to design and predict the behavior of the system.

9. Model testing tools - various software environments that check the received systems to minimize errors, as well as check models for integrity and compliance with established requirements.

10. Process control system (СУТП) - acts as a "control panel", implements interaction with sensors, sending them commands about the necessary changes

or stopping work, for example, when analyzing input data and a critical situation occurs.

Now let's consider a generalized algorithm for developing and using a digital twin for diagnosing the technical condition of an industrial robot[8,9]. The main purpose of using a digital twin is to determine the technical condition of an industrial robot and the remaining service life of its elements, based on a combined study of data from control systems, as well as modeling the operation of units based on real physical indicators, as shown in Figure 3.

The algorithm for achieving this goal includes four stages:

1. The first stage consists of advanced physical modeling of the robot. In addition to kinematic and dynamic characteristics, it is necessary to integrate a set of virtual sensors into the simulation model.
2. The second stage is focused on the synchronous simulation setting of the physical models of the operation of the key components of the robot. Since simulation of the operation of nodes is used to calculate their useful life, models must be constantly tuned to avoid possible deviations between their real and simulated functionality.
3. The third stage involves modeling the actions of the robot based on physical data, using the collected parameters of the sensors and the controller as input.
4. The fourth step combines the results of the simulation and controlled data of the robot, which will determine its current state and predict the remaining service life.

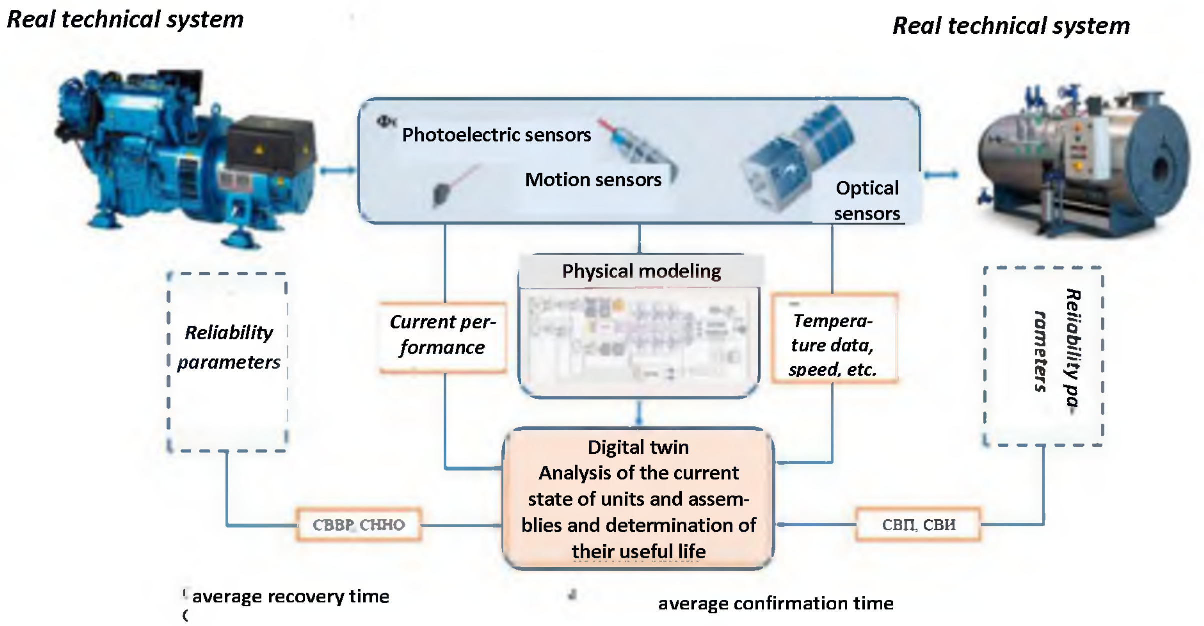

Fig. 3 – Scheme of combined simulation of industrial work using physical systems and a digital twin

Thus, summarizing the obtained results, we note that the digital twin has a significant efficiency potential for the development of a predictive maintenance algorithm that can be implemented in the real equipment controller. The process of technical diagnostics based on the digital twin can be automated, which will allow it to quickly adapt to changing conditions, processed materials and equipment configuration.

In promising studies, it seems appropriate to consider in more detail the stages of the proposed algorithm for the development and application of a digital twin for diagnosing the technical condition of an industrial robot.

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КОМПЛЕКС ПРОГРАММПО-АППАРАТПЫХ РЕШЕНИЙ ДЛЯ АЭРОГИДРОДИНАМИЧЕСКОЙ ЛАБОРАТОРИИ

И. П. Бойчук, кандидат технических наук, доцент
А.В. Гринек, кандидат технических наук, доцент
А.В. Корнев, кандидат технических наук, старший научный сотрудник (Украина)
С.Ю. Алексянц, курсант
А.М. Фищенко, курсант
М.А. Модина, кандидат технических наук, доцент

В статье показан опыт разработки контрольно-измерительной и регистрирующей аппаратуры для аэрогидродинамической лаборатории Государственного морского университета им. адм. Ф.Ф.Ушакова (Новороссийск). Проанализированы существующие методы измерения и регулирования скорости потока. Показана схема и принцип работы микропроцессорного устройства для регулирования двигателя постоянного тока в составе аэродинамической трубы. Описана схема подключения датчиков, регулятора частоты и дополнительных устройств. Показана разработаннаямодель устройства в среде SimInTech и элементы программного управления устройством, приведены результаты моделирования системы. Определенные показатели качества системы регулирования показали удовлитворительные результаты. Предложена схема реализации аэродинамических весов на гироскопическом датчике с акселерометром.

Ключевые слова: аэрогидродинамическая лаборатория, измерение потока, регулятор, двигатель постоянного тока, аппаратура, аэродинамические весы

COMPLEX OF SOFTWARE AND HARDWARE SOLUTIONSFOR AERОHYDRODYNAMIC LABORATORY

I. P. Boychuk, A. V. Grinek, A.V. Kornev, S.Y. Aleksyanc, A.M Fishchenko, M. A. Modina

The article shows the experience of developing instrumentation and recording equipment for the aerohydrodynamic laboratory of the Admiral Ushakov Maritime State University (Novorossiysk). The existing methods for measuring and controlling the flow rate are analyzed. The scheme and principle of operation of a microprocessor device for controlling a DC-motor as part of a wind tunnel is shown. The scheme of connecting sensors, frequency controller and additional devices is described. The developed model of the device in the SimInTech environment and elements of software control of the device are shown, the results of the system simulation are presented. Certain indicators of the quality of the regulatory system showed satisfactory results. A scheme for the implementation of an aerodynamic balance based on a gyroscopic sensor with an accelerometer is proposed.

Key words: aerohydrodynamic laboratory, flow measurement, regulator, DC motor, equipment, aerodynamic balance.

Введение

Для изучения гидродинамики судов [1, 2] получило широкое распространение использование бассейнов, в которых модели судов буксируются по воде тележкой, движущейся в воздушной среде по рельсам, проложенным по краям бассейна. В бассейнах исследуется не только прямолинейное движение судов, но и круговое.

Разработка регистрирующей аппаратуры [3, 4] и системы автоматического управления в составе аэрогидродинамической лаборатории обеспечивает возможность получения необходимых параметров среды для проведения исследований и тем самым обеспечивая получение более точных значений [5] в течении продолжительного периода проведения исследования аэрогидродинамических свойств объектов.

Целью работы являетсяразработка средств регистрации выходных значений потока воздуха в аэродинамической трубе, реализация автоматической системы управления нагнетающего устройства и обеспечение считывания параметров с исследуемого объекта. А также определение возможности использования выбранных методов