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3D VISUALIZATION OF THE STATE OF THE NEW SECURE CONFINEMENT OF CHNPP USING MICROSERVICE ARCHITECTURE

The purpose of this paper is to develop a software architecture for 3D visualization of information about the state of the New Safe Confinement (NSC) of the Chernobyl Nuclear Power Plant using microservices technology. The NSC was built to protect the population and the environment from the consequences of the accident at the ChNPP and to ensure the implementation of works aimed at transforming the "Shelter" facility into an environmentally safe system. The NSC is a large and complex system, the activity of which is ensured by a large number of different subsystems under the control of the Integrated Management System (IMS). However, existing information systems do not provide a sufficient level of capabilities for information visualization, forecasting and decision-making support, which determines the urgency of developing new information technologies. Given the long period of operation of the NSC, for a comprehensive solution to this problem, it is advisable to develop its digital twin, one of the functions of which is 3D visualization of information about the state of the NSC. The non-functional and functional requirements for the 3D visualization software were formed, on the basis of which its microservice architecture was developed as part of the architecture of the digital twin of the NSC. A database model of the visualization service was developed and a management system was chosen for it. Considering the large volumes of data on NSC, it is recommended to use Column-based systems to manage such databases, however, to create a prototype of the software product, you can use a relational model under PostgreSQL management. For modeling building structures, the 3D model was developed in the ArchiCAD system with the ability to display data at certain points in the three-dimensional coordinate system. The application of microservices technology ensures the flexibility of the developed architecture, the possibility of its scaling and further development throughout the long period of operation of the NSC as a component of its digital counterpart.

Keywords: digital twin; new safe confinement of ChNPP; software architecture; 3D visualization; information system; information technology.

Introduction

The accident at the Chernobyl nuclear power plant (ChNPP), which occurred in April 1986, led to the need for the urgent construction of protective structures capable of preventing the spread of radioactive contamination. A Shelter Object (SO) was built, which isolated the destroyed fourth power unit of the ChNPP from the environment. However, the operational time of the SO was only 30 years, so Ukraine, together with the international community, developed new approaches to combating the consequences of the accident [1]. After analyzing a number of options and holding a competition, it was decided to build a new protective structure called "New Safe Confinement" (NSC), which was supposed to isolate the SO from the environment and ensure the possibility of carrying out production processes to transform the SO into an environmentally safe system. In 2019, the NSC was commissioned. The main element of this protective structure is the Arch, which has a height of approximately 109 m, a width of 257 m and a length of 150 m. The planned life of the Arch's cladding is 100 years, provided that certain humidity levels are maintained [2].

Analysis of the characteristics of the NSC allows this object to be classified as a large and complex system, and this structure is unique in the world. Taking into account the large number of operational tasks in which personnel must make decisions on the management of NSC processes under conditions of non-stationarity and the influence of various factors, taking into account radiation and nuclear hazards, NSC information systems must meet high requirements for speed, accuracy and reliability of performance of functions, have the ability to development and improvement, which determines the relevance of research in this area.

Analysis of recent research and publications. Monitoring and management of the state of the NSC is carried out by a specialized Integrated Management System (IMS), which after launch was also connected to the Integrated Automated Control System (IASC) of the OU [3; 4]. Research is being conducted to improve the possibilities of monitoring the state of NSCs based on CFD (Computational Fluid Dynamics) models [5], and their application in solving the problems of managing individual processes [6].

Taking into account the long period of operation of the NSC, approaches to the development of its IT architecture are proposed, taking into account such concepts as "Continuous Development", "Continuous Integration" and "Continuous Deployment" [7].

It should be noted that the existing management information systems of the NSC have an insufficient level of information visualization, forecasting and decision-making support capabilities. However, there is a need for 3D visualization for information analysis and modeling of various production situations, work is underway to create 3D visualization systems for the process of disassembling SO structures [8]. A possible option for a comprehensive solution to this problem is the application of the theory of digital twins.

There are several software products that allow you to automate the construction of digital twins with 3D visualization capabilities. The Amazon Web Services IoT TwinMaker software environment (AWS IoT TwinMaker) is used to create digital twins of real systems and is flexible enough to import existing 3D models from CAD files, automated design systems (CAD) and building information modeling (BIM) [9]. A virtual model is a graph that structures and organizes information about a digital twin for ease of access and understanding. The provided AWS IoT TwinMaker scene builder and defined simple 3D tools are used to import visual assets into the scene and position them according to the physical environment, such as a factory and its equipment. Interactive overlays of video and sensor data from connected data sources, analytics from connected machine learning (ML) and modeling services, and maintenance tags and work documents provide up-to-date spatial visualization [9]. The Grafana plugin provides custom rendering panels, including a 3D scene viewer and dashboard templates, as well as a data source component for connecting to custom digital twin data, enabling the rapid creation of 3D-enabled applications [10]. This plugin can also be used to build applications using the fully managed open source service Amazon Managed Grafana. Built-in security features to meet enterprise governance requirements, including single sign-on, user and group data access control, and audit reporting [10]. These tools are quite powerful, but NSC is a unique object, so the available libraries do not contain models of its components. In addition, the use of cloud services for objects with such a level of radiation and nuclear danger, especially in the conditions of martial law, is not appropriate, which indicates the need for research and the use of modern software engineering tools to solve the problem [11].

The purpose and objectives of the study. The purpose of this paper is to develop a software architecture for 3D visualization of information about the state of the NSC using microservices technology, considering this software as a component of a digital twin of the NSC. To achieve the goal, it is necessary to form the requirements for the 3D visualization software module, form its architecture, and choose tools of implementation.

The Main Part

In order to comprehensively solve the problem of improving the capabilities of NSC information systems in terms of 3D visualization, forecasting and decision-making support, a digital twin architecture is proposed. The proposed architecture of the digital twin is multi-level and built according to the modular principle, which allows it to be flexibly supplemented depending on needs. To develop the components of a digital twin, it is recommended to use a microservice architecture based on secure information transfer protocols [12].

The implementation of 3D visualization of the state of the NSC involves the display in three-dimensional space of data on the actual or predicted values of the quantities characterizing it. Actual data on the state of the NSC are recorded by the existing technical and software of the ISU, stored in its database and transferred using special interfaces to the data structures of the digital twin. The predicted data on the state of the NSC are the result of the use of models that are part of the digital twin. At the first stage of creating a visualization module, only actual data, current or historical, is considered, but the architecture of the module should provide the ability to work with forecasted data as well.

Given the long life of the NSC, the architecture of its digital twin should provide the possibility of continuous development and improvement. One of the modern software engineering approaches that meets these requirements is microservice architecture. It determines that the system is formed as a set of loosely connected services that perform separate functions, which ensures its flexibility, scalability and ease of deployment [11]. Therefore, on the basis of microservices technology, the architecture of software for 3D visualization of the state of the NSC, shown in fig. 1, was developed.

As can be seen from fig. 1, the presented software is a component of the NSC's digital twin. The functionality of this software takes into account the following requirements:

- 3D visualization of the building of the NSC and SO, with the possibility of changing the scale, rotation, demonstration of layers of building structures;
- 3D demonstration of sensor location points (measurement points) and their indicators;
- depending on the settings, when displaying information for the period, show the minimum, maximum, average value, and root mean square deviation, with the possibility of choosing several options;
- colored illumination of the values of the sensor indicators depending on the configured value intervals (green, yellow, red);

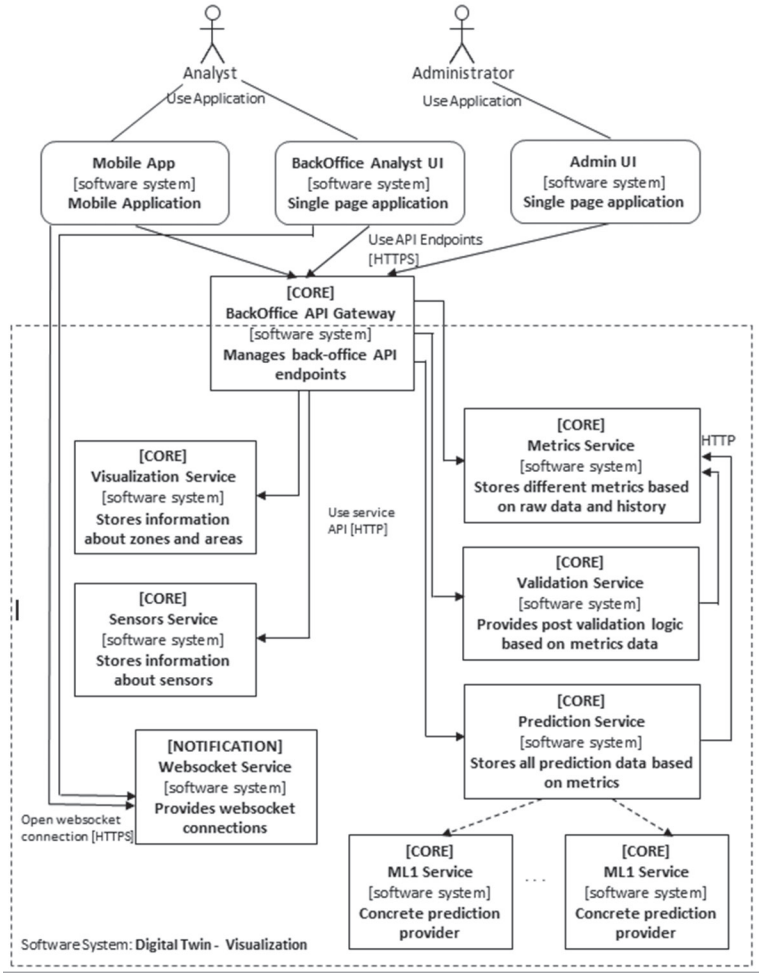

Fig. 1. Software architecture for 3D visualization of the state of the NSC

• options for selecting sensor values by sensor type, set of sensors (measuring points), ISU subsystem, respectively, illumination and output of values work on the selected subset of data.

The generalized service structure of the developed software for 3D visualization of the NSC state is shown in fig. 2.

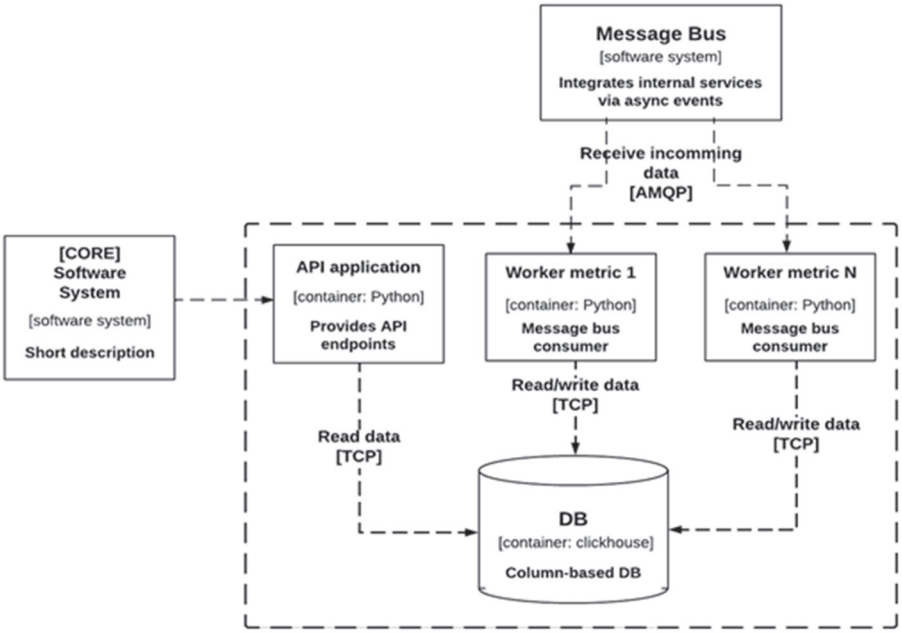

Fig. 2. The generalized structure of the software service for 3D visualization of the NSC state

The developed database of the service stores information about measured values, measurement points with three-dimensional coordinates, sensors and their location, NSC subsystems, sensor values at certain moments of time. Considering the large volumes of data on NSC, it is recommended to use Column-based systems for managing such databases, which, due to the presentation of information in the form of columns, ensure its more efficient processing. To create a prototype of a software module for 3D visualization of the NSC state, you can also use a relational model under the management of the PostgreSQL system, which is efficient for structured data and is free.

ArchiCAD software complex was used for 3D modeling of building structures of NSC. With its help, a NSC model in ifc format was developed, which includes the possibility of displaying information about sensor values at certain measurement points with reference to three-dimensional coordinates. A visual presentation of the model is shown in fig. 3.

The software can use this model in the ifc format to output the values of the quantities from the database, which allows to implement a 3D visualization of the state of the NSC for both actual and forecast data.

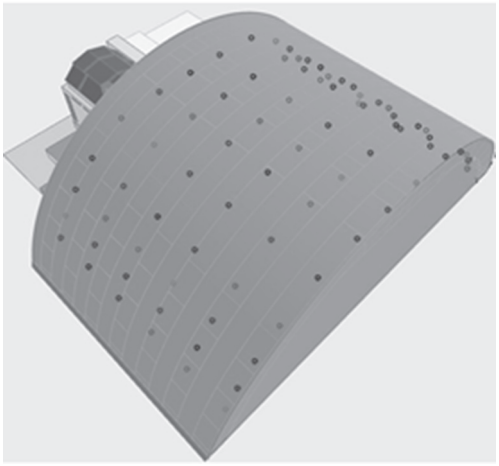

Fig. 3. An example of 3D visualization of the NSC state

Conclusions

Thus, in this work, on the basis of functional and non-functional requirements, a software architecture for 3D visualization of information about the state of the NSC using microservices technology is developed. A database model of the visualization service was developed and a management system was chosen for it, taking into account the large amount of information about the object. For modeling building structures, a 3D model was developed in the ArchiCAD system with the ability to display data at certain points in the three-dimensional coordinate system. The application of microservices technology ensures the flexibility of the developed architecture, the possibility of its scaling and further development throughout the long period of operation of the NSC as a component of its digital twin.

References

1. ***Об'єкт*** *«Укриття»: 30 років після аварії: монографія / В. О. Краснов, А. В. Носовський, В. М. Рудько, В. М. Щербін // НАН України, Ін-т проблем безпеки АЕС. Інститут проблем безпеки АЕС, 2016. 512 с.*

2. ***Новый*** *безопасный конфайнмент чернобыльской АЭС (расчетно-экспериментальный анализ при проектировании и эксплуатации): монография / П. Г. Круковский, М. А. Метель, Д. И. Скляренко [и др.]: под ред. П. Г. Круковского, В. А. Краснова, В. П. Сулимова. Киев, ООО «Франко Пак», 2019. 300 с.*

3. ***Об'єкт*** *«Укриття» в умовах нового безпечного конфайнмента / В. О. Краснов, А. В. Носовський, С. А. Паскевич, В. М. Рудько: за заг. ред. А. В. Носовського. Чорнобиль: ІПБ АЕС НАН України, 2021. 344 с.*

4. ***Сверчков С. Ф.*** *Интегрированная автоматизированная система контроля объекта «УКРЫТИЕ» // Проблеми безпеки атомних електростанцій і Чорнобиля. 2019. Вип. 32. С. 62–66.*

5. ***Разработка*** *мониторинга состояния нового безопасного конфайнмента на основе CFD-модели (для поддержки проекта преобразования объекта «Укрытие») / П. Круковский, А. Полубинский, П. Кончуковский [и др.] // Проблеми зняття з експлуатації об'єктів ядерної енергетики та відновлення навколишнього середовища (INUDECO 18): зб. матеріалів III Міжнар. конф. (25-27 квітня 2018 р., м. Славутич). Чернігів: ЧНТУ, 2018. С. 165–171.*

6. ***Розробка*** *спеціального програмного математичного забезпечення управління вентиляційними установками нового безпечного конфайнменту ЧАЕС / Y. Pysmennyy, Y. Havrylko, P. Krukovskyi [et al]. // Nuclear & radiationsafety. 2022. 2(94). С. 35–43.*

7. ***Kratz B., Wieduwilt F., Saveliev M.*** *Pillars for Establishing a Durable and Future-Proof IT Architecture Maturing Along with the NSC: Approaches from Continuous Integration to Service Mesh Mathematical Modeling and Simulation of Systems // Selected Papers of 16th International Scientific-practical Conference, MODS, 2021 June 28–July 01, Chernihiv, Ukraine. P. 43–57.*

8. ***Центр*** *візуалізації ЧАЕС [Електронний ресурс]. URL: https://www.youtube.com/watch?v=txnoidoZzEk. (дата звернення: 14.09.2022).*
9. ***AWS IoT*** *TwinMaker Features [Електронний ресурс]. URL: https://aws.amazon.com/ru/iot-twinmaker/features5. / (дата звернення: 26.09.2022).*
10. ***Dashboard*** *anything. Observe everything [Електронний ресурс]. URL: https://grafana.com/grafana/ (дата звернення: 26.09.2022).*
11. ***Vikram*** *Murugesan. Microservices Deployment Cookbook. Packt Publishing, 2017. 378 с.*
12. ***Loboda P. P., Starovit I. S.*** *Architecture of the digital twin for the New safe confinement of the CHNPP // Зв'язок. 2022. №2. С. 22–26.*

П. П. Лобода

3D-ВІЗУАЛІЗАЦІЯ СТАНУ НОВОГО БЕЗПЕЧНОГО КОНФАЙНМЕНТУ ЧАЕС З ВИКОРИСТАННЯМ МІКРОСЕРВІСНОЇ АРХІТЕКТУРИ

Метою статті є розроблення архітектури програмного забезпечення для 3D-візуалізації інформації про стан нового безпечного конфайнменту (НБК) ЧАЕС з використанням технології мікросервісів. НБК було збудовано для захисту населення і довкілля від наслідків аварії на ЧАЕС та для забезпечення виконання робіт із метою перетворення об'єкта «Укриття» на екологічно безпечну систему. НБК є великою та складною системою, діяльність якої забезпечує велика кількість різних підсистем під керуванням Інтегрованої системи керування (ІСК). Однак наявні інформаційні системи не забезпечують достатній рівень можливостей для візуалізації інформації, прогнозування та підтримання ухвалення рішень, що зумовлює актуальність розроблення нових інформаційних технологій. З огляду на тривалий період експлуатації НБК для комплексного вирішення цієї задачі доцільно розробити його цифровий двійник, однією з функцій якого є 3D-візуалізації інформації про стан НБК. Сформовано нефункціональні та функціональні вимоги до програмного забезпечення 3D-візуалізації, на основі яких розроблено його мікросервісну архітектуру як частину архітектури цифрового двійника НБК. Розроблено модель бази даних сервісу візуалізації та вибрано для неї систему керування. Беручи до уваги великі обсяги даних щодо НБК, для керування такими базами даних рекомендується застосовувати Column-based системи, однак для створення прототипу програмного продукту можна використати реляційну модель під керуванням PostgreSQL. Для моделювання будівельних конструкцій розроблено 3D-модель у системі ArchiCAD з можливістю відображення даних у певних точках в системі тривимірних координат. Застосування технології мікросервісів забезпечує гнучкість розробленої архітектури, можливість її масштабування та подальшого розвитку впродовж всього довгого періоду експлуатації НБК як складової його цифрового двійника.

Ключові слова: цифровий двійник; новий безпечний конфайнмент ЧАЕС; архітектура програмного забезпечення; 3D-візуалізація; інформаційна система; інформаційна технологія.