Stages of Design of Digital Twin for Local Enterprise

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Abstract. The work is devoted to the consideration of the stages of development of a digital twin for the local enterprise. With the aid of the digital twin it is possible to manage the enterprise, control problems in it, ensure the normal functioning of the enterprise objects due to the monitoring of a status of facilities and equipment based on big data obtained from Industrial IoT-sensors, as well as the monitoring of performance and current status of employees on the basis of the interpretation of bio-signals obtained in real time. The plant for preparation of super-viscous oil with disposal facilities was chosen as a local enterprise. This data is collected for the unit of predictive analysis and prediction in real time of pre-emergency situations for the rapid taking action to prevent these threats. In order to develop a plausible prototype of the digital twin of the enterprise, Unity cross-platform development environment for computer games was used.

Keywords: Digital Twin, Virtual Reality, Augmented Reality, Unity Real-Time Development Platform

1 Introduction

Digital systems for personal use have long moved from dry data to the more natural form of the information delivery to a user. Production systems tend to the same and, it seems, due to technological progress in the field of automation finally step over the abyss, after which the control systems become inherently more complex, but at the same time easier for direct human use. The improvement of such systems will require joint efforts of specialists of mathematical, computer, and, of course, psychological sciences, but will provide a huge increase in the efficiency of enterprises, as well as will contribute to the mental comfort of people working directly with the system.

Digital economy and the related terms such as digital twin, digital copy, digital double, digital transformation, digitalization are already firmly established in the terminology of both IT-specialists and economists, but there are different interpretations of them. “A Digital Twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin” [1]. According to this definition, in our understanding digital twin is an interactive 3D representation using user-friendly visual interfaces (clear and needless for additional interpretation) of the mathematical model of the technological object, updated in real time on the basis of information from the array of sensors. According to the vice president of GE Software Research Colin J. Parris, “Digital twin is a living model that drives a business outcome” [2].

Besides the remote comfortable work of top management with the current state of the enterprise, for the work of middle managers and their subordinates, workforce in the production itself, it is necessary to develop applications that allow to get the same interactive data in augmented reality format. Thus, the aim of the research is the development of the most effective and realistic simulation of the work of the local enterprise in real time, simulation of the sensors that monitor the condition of facilities and equipment, as well as recording of the status of employees; the creation of functionality of simple and intuitive user interface (UI/UX), data generation on the basis of which visualization of simulation of work of the enterprise will be implemented.

The remainder of this paper is organized as follows. In Section 2, there is a summary of the literature on digital twin research. Section 3 introduces the digital twin framework for the concrete enterprise, including the architecture and functional development. In Section 4, a case study shows the emergence of new problems while developing the digital twin framework. Conclusions are discussed in Section 5.

2 Related Works

The term “Twin” appeared as part of NASA's Apollo program for which two space crafts were built, one of which remained on earth to display the condition of the first one and was called “the twin” [3]. Usage of a digital twin creates new opportunities for improving business processes of companies due to the accurate and timely data. Nowadays the concept of a digital twin is considered actively as it is a strategic pathway. According to [4] a digital twin is a powerful tool which has the following advantages: Visibility, Predictive, What if Analysis Understand and explain behaviours, Connect disparate systems such as backend business applications. Described advantages provide great prospects for applying of a digital twin. However, the literature review reveals, that the development of the digital twin is still at its infancy as literature mainly include concept papers, but some concrete applied case-studies already exist.

The authors of [5] consider the concept of a digital twin in a whole, its application in product design, production scheduling, production itself and in prediction of normal and critical events. The article [6] specifically describes the application of the digital twin for modeling of the construction work of the railway station buildings for King’s Cross station. The results of this study can provide construction participants with reasonable guidance on the use of the digital twin in railway station projects for the planning, design and operation of an economical, efficient and environmentally friendly construction project. The work [7] describes some possible cases of usage of a digital twin for the wiring harness for Mercedes-Benz Cars. Digital twin allows to find vehicle faults caused by damage of the wiring harness, that consequently makes it possible to solve the problem quickly and cost-effectively. As for the petrochemical industry, the research [8] represents approaches to time series data processing as well as frequency unification, time lag issues, and the demand for immediacy for modelling of a digital twin.

The paper [9] concerns the use of sensors for Industrial Internet of Things and represents a SmartJacket. This solution is a jacket that carries data collecting sensors and safety elements such as RGB LED sleeve strips. Upon the occurrence of a specific event RGB LED sleeve stripe of the corresponding color illuminates, alerting the employee about the emergency situation.

An essential part of a digital twin is an ability to forecast some emergency situations in an enterprise. According to [10], a digital twin propose a solution of diagnostics (static and dynamic), optimization and prediction tasks due to the following components: the initial digital model, describing the processes and relations between some of control parameters and being optimized parameters; the knowledge base, filled with initial information about desired KPI; the database, able to store current data from control object; the ability to connect to DCS / PSS / ICS to send them a control signals; the execution environment, which can run digital models; the chosen algorithms of system identification and optimization. The paper [11] provides the model of emergency situations and accidents prediction for reduce the frequency of their occurrence at building sites. The authors analyzed data obtained from environmental sensors and generated association rules that represent the relationship between the accident types and causes. For this reason, preprocessing, association rule generation, and visualization are executed step by step. An experimental implementation using open-source R is conducted for demonstration of the accident prediction model. The investigation [12] provides an architecture framework to implement the cyber-physical production system, that monitors quality in metal-casting processes and predicts the occurrence of factory situations in real time based on the technologies such as the IoT, big data, and simulations. Moreover, such system acts as a coordinator to form optimal decisions related to the re-creation of production schedules.

In the current article we represent our own vision of a digital twin on the example of the development of the plant for preparation of super-viscous oil with disposal facilities.

3 Our Approaches

One of the small local enterprises in the Republic of Tatarstan was chosen as a preliminary site for the implementation of digital transformation of the enterprise production process management. The plant for preparation of super-viscous oil with disposal facilities "Kamenka" [13] was chosen as it provides not only the relative simplicity of a technical device, but also the ability to simulate all technological processes according to data obtained from IoT-sensors. A comfortable realistic three-dimensional interface for monitoring the situation at the site was developed for this enterprise. The architecture of the developed system is described below.

3.1 Architecture of the System

Database. For the specific solution database will have four entities (tables) such as User, Requirement, Notification, Task. More detailed database architecture is represented in the Figure (see Fig. 1).

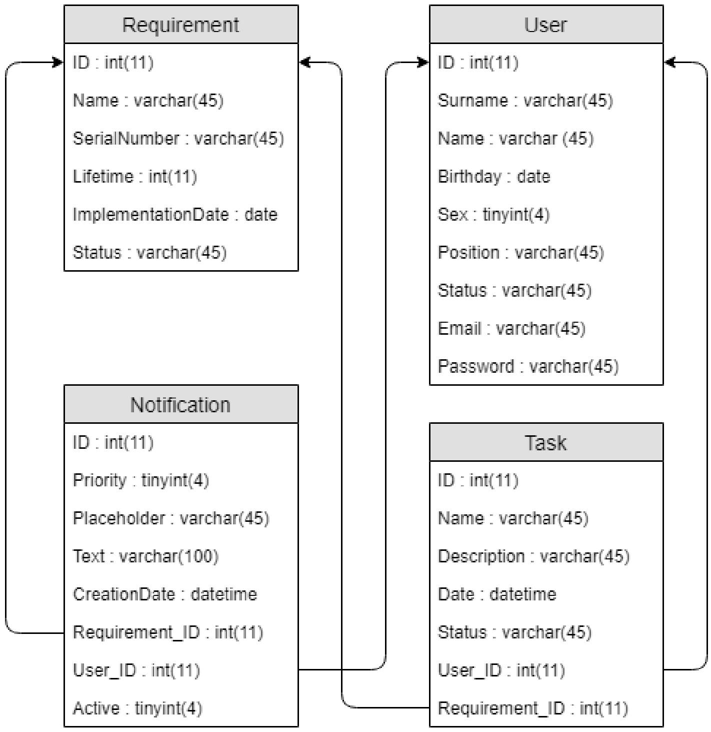

Fig. 1. Database architecture

The table *User* contains information about each member of staff, personal information, including username and password for authentication in the system. It is assumed that each employee will have access to the system through the application on a mobile device, which the employee will carry with him throughout the time spent in the enterprise, in other words, the entire working day. He will receive notifications (*Notification*) via this application. Notifications are simple messages from the administrator or other employees, or tasks (*Task*) that need to be executed (prevent or fix machinery breakdown, or take the place of another co-worker). The table *User* also includes such information as surname, name, date of birth, sex (male/female), job role, work status (busy/free), email and password.

The table *Requirement* contains all information about equipment of the enterprise including tank vessels, tubes, collectors, etc. It is assumed that each equipment introduced into the enterprise must be registered in the system, which will store such information as the equipment identification plate (category), serial number, run life, installation date and status (working properly/malfunction/exited run life). If the status of the equipment is “malfunctioning” or “exited run life”, an administrator receives an alert and creates a task (*Task*) to repair or remove the equipment from production. The task must be executed by someone of the employees.

The table *Notification* contains information about equipment or employee status notifications, and it is associated with the *User* (User_ID) and *Requirement* (Requirement_ID) tables. Besides ID and Foreign Key the entity of a notification have the following attributes: priority (deviation from the norm is critical/not critical), title (by which the deviation is caused), notification text, the date of the deviation appearance and activity (the problem is fixed/not fixed).

Finally, the table *Task* contains information about tasks that are sent to employees for execution, and it is associated with the *User* (User_ID) and *Requirement* (Requirement_ID) tables. When an administrator receives automatic notifications about the status of enterprise’s facilities, he creates a task object. It is assumed that employees will choose a task from the list of tasks: “accept”, or skip the incoming task, i. e. “reject”. Thus, the entire workflow will consist of the execution of tasks that income on the mobile devices. It will allow to optimize production activities and save time. The *Task* entity will consist of attributes such as a task title, description, creation date, and status (completed/not completed).

The database architecture should contain status of all features such as Prediction entity including workload, integrator, cost part of the object for predicting the possibility of equipment replacement. The database architecture should be also extended with UserState entity, which has information about health and environment around the employee. This information includes data obtained from sensors.

Database query. All database queries are implemented in the *DbMySQLUtils* class. They act as methods, so inheriting from this class it is possible to access the database. Since some queries take a good deal of time and slow down the main stream, requests are sent to the database in separately created streams. For this reason, *System.Threading* utility is used.

All data from the database is read after a specified period of time to remove excessive load from the database. This algorithm is described in the *ReadAllInfoThread()* method (see Fig. 2). When starting the application, the system will immediately read the data, then update the data again after a specified pause, and so on. If other queries to the database (INSERT, UPDATE, DELETE) are executed, the stream, that reads all data, will stop, then the stream with a certain query will be started and then the *ReadAllInfoThread*() method with the newly created stream will be started again.

```
public void ReadAllInfoThread()
{
    var startTimeSpan = TimeSpan.Zero;
    var periodTimeSpan = TimeSpan.FromMinutes(1);

    timer = new Timer((e) =>
    {
        thread0 = new Thread(delegate ()
        {
            users = ReadUsers();
            requirements = ReadRequirement();
            notifications = ReadNotification();
            tasks = ReadTask();

            if (u != users)...
            else...

            if (r != requirements)...
            else...

            if (n != notifications)...
            else...

            if (t != tasks)...
            else...

            u = users;
            r = requirements;
            n = notifications;
            t = tasks;
        });
        thread0.Start();
        thread0.IsBackground = true;
        Debug.Log("start0");
    }, null, startTimeSpan, periodTimeSpan);
}
```

Fig. 2. Method that reads all data from the database

Movement of employees. The movement of employees will be carried out according to their tasks: the employee, having received an alert (a call from a head, automatic notification of the problem, scheduled tasks, etc.), must go to the location of the specified division.

For debugging, the procedure of the current location of the employee was simulated, which was implemented through the serialization of data into a JSON-file of several checkpoints. In the future, the movement will be implemented not via coordinates from the JSON-file, but relative to deviations from the norm of equipment and staff conditions, emergency situations, and other factors.

Indicators of equipment sensors. Serialization and deserialization of indicators of sensors of the equipment were implemented by the same principle. For tubes, tanks, collectors two indicators were selected – pressure and temperature. The condition of the equipment will be determined on the basis of these indicators. Each indicator has three zones: green, yellow and red. Each zone is an interval in which one or another indicator can be located. The green zone means that the indicator is normal, the yellow zone – a slightly deviation from the norm, the red one – a critical deviation from the norm.

Indicators of employee sensors. Similarly to serialization and deserialization of equipment sensors data of employees are recorded and read. First of all, it is pressure, pulse and temperature. Employee pressure is measured in two values: upper indicator (arterial tension) and lower indicator (venous blood pressure). Both indicators are measured in millimeter of mercury (mm Hg). The temperature is measured in standard degrees Celsius (°C). Pulse is measured in beats per minute.

However, for comprehensive workplace safety in the oil industry with the aid of sensors also it is possible to measure the electrocardiogram, record the respiratory rate and heart rate, body position and activity of the staff, as well as to supplement the system with sensors of environmental quality, for example, sensors that monitor the presence of poisonous gas in the working environment, that provides monitoring of the health of the employee. Moreover, with the aid of the alarm installed in the wearable device, the employee can be timely warned about dangerous situations or be able to warn about them by pressing the button.

3.2 Functional Development

Zoom and view from different angles. An important part of the implementation of digital twins are natural interfaces that give mental comfort to the user working directly with the system [14].

The zoom implementation for the desktop version was programmed as standard via a computer mouse Scroll Wheel. Viewing from different angles is implemented via User Interface (UI) buttons. When being clicked by a computer mouse wheel on a particular employee or equipment the point of click becomes closer.

View employee data and equipment information. It was necessary to add the ability to view employee data and equipment information with the aid of using entity-relationship model from the database (*Requirement* and *User*). The fields in which this information will be displayed are panels *Requirement InfoPanel* and *Employee InfoPanel* (see Fig. 3), located on the right side of the screen. These panels will appear as often as a user clicks the left mouse button on the corresponding digital object.

Fig. 3. Current employee data

Notifications about problems. When a problem occurs in the system (sensor indicators are in the red or yellow zone), a notification object (*Notification*) appears. Depending on the degree of criticality of each indicator, a certain algorithm determines in which zone the overall condition of the equipment or employee is located. Moreover, depending on the indicators of previous notifications, the decision is made whether to deactivate (disable) the latest notifications. Deactivated notifications are notifications included in the archive. They can be viewed in the employee or equipment card by clicking on the button with the warning icon (triangle with an exclamation mark). Notifications related to an equipment or employee can be sorted by the following categories: All messages, Accepted, Rejected, and Recent. When is being hovered by the mouse over the warning button on the main scene, a drop-down list with the same categories appears (see Fig. 4).

Label is an instant visualization of the status of an employee or equipment. In order to instantly determine the status of an employee or equipment, the label tool is developed. The label appears on the top of the object, and can be yellow if the deviation is not critical, red – in case of critical deviation (see Fig. 5).

Fig. 4. Drop-down list of notifications

Fig. 5. Employee with a warning label

4 Emergence of New Problems

The problem of overload of connection of the application with the database occurs when there are too many requests sent to the server. In order to avoid this problem it was necessary to develop an algorithm by which all queries will be distributed in accordance with the priority given to them. Thus, a queue of queries is created, where the higher priority ones are executed at the beginning. If the amount of data in the database is too large, it is necessary to distribute it to several different servers. The next step in the implementation of the pilot application will be solving this load problem to determine the load limits for the physical architecture organization.

5 Conclusion

To sum up, digital twin is in the process of development and requires the introduction of many functions for the correct operation of the system. At this stage, first of all, it is necessary to solve the problem of overload of the communication channel with the database. In addition, it is necessary to add a display function and a corresponding sort of a notification on the stage-screen with notifications and on *Requirement InfoPanel* and *Employee InfoPanel* panels.

However, besides the current problems, many important tasks were solved: designing the application architecture, functionality for editing and displaying information about equipment and employees, creation of notifications and functional content of the scene such as scaling, camera movement, displaying UI/UX elements when pressing or hovering over certain buttons, as well as automatic display of warning labels in places of problems.

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