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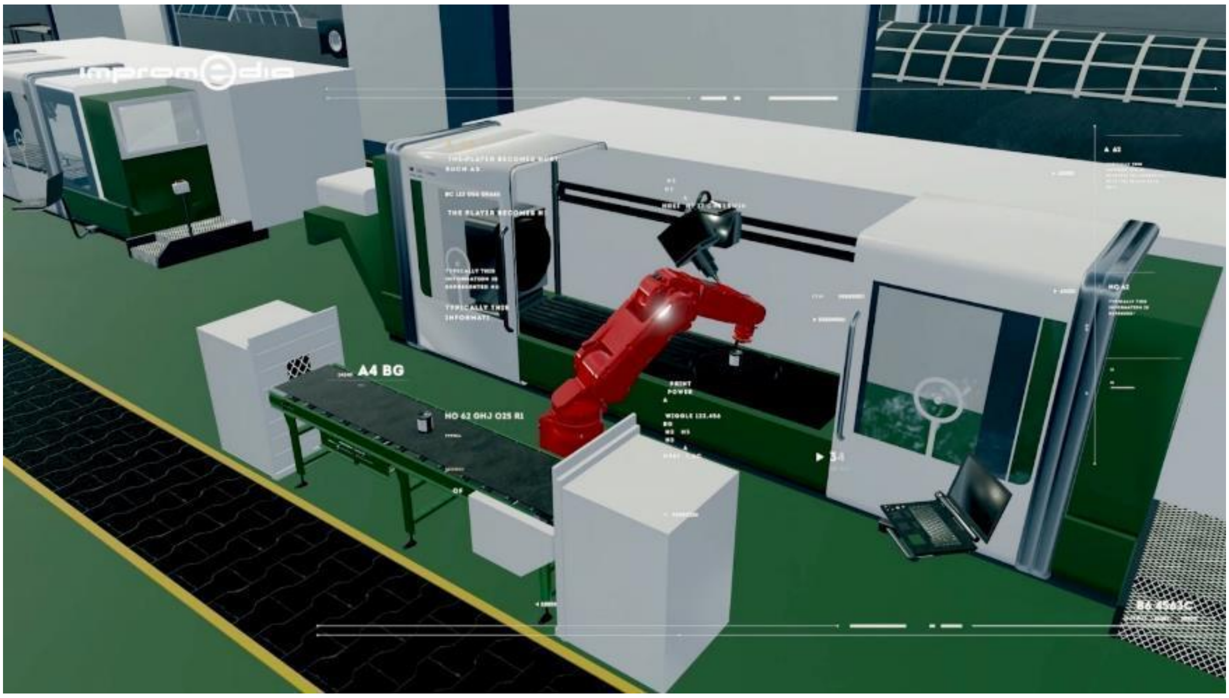
Platform for coordinating material and information flows in Industry 4.0

- *Abstract* -



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Abstract

In recent years, due to the computerization of manufacturing processes and the increasing use of digital prototypes of the “digital twin” type, we are witnessing an exponential increase in the need for coordination and integrated management of information flows alongside material ones. It is necessary to develop innovative technologies, equipment, methods for collecting, transmitting, managing, processing, and visualizing large data to ensure the transmission of data from real system monitoring to digital twin and digital twin to real system commands.

If the assisted design module generates the virtual prototype of the product, the flow management module that is the central node of this platform generates the virtual prototype (digital twin) of the manufacturing architecture. By simulating the material flows at the level of this virtual prototype, diagnoses can be obtained, and solutions can be validated every time changes in the manufacturing architecture occur as a result of the introduction of new products in production.

The virtual prototype of the manufacturing architecture is also the main optimization tool when a preliminary manufacturing architecture needs to be finalized and validated. It can be seen that in its applications in industrial engineering this module practically particularizes a series of general optimization algorithms in the theory of material flows (Cotet CE et al., 2014). The central module of the platform proposed in this thesis will also ensure the management of information flows between the virtual prototype and the real system.

Objectives of the doctoral thesis

Starting from the analysis of the context of the fourth industrial revolution and of the existing software solutions on the market in the IIoT area (Industrial Internet of Things), the research carried out in this thesis starts from a different innovative approach, in the implementation of an IIoT platform that would offer an alternative in the process of collecting, storing and processing data but also in the way of viewing and interacting with them.

The main objective of the research conducted in the thesis focused on the design and development of a collaborative platform that uses virtual reality (VR) to allow visualization, simulation and optimization of material and information flows in manufacturing architectures.

To achieve this main objective, it was necessary to approach some **secondary objectives** of the research, as follows:

- preliminary theoretical research on the concept of Industry 4.0, the current state of industrial Cloud platforms, virtual and augmented reality.
- developing a method for transmitting and storing large data, using PNG images as a storage medium.
- development of a message-based middleware application for synchronizing virtual machines.
- development of a vision system for monitoring production lines.
- integration of a collaborative virtual reality platform, as a development environment,

- designing integrated applications for this platform.
- extending the scope of the platform.

The structure of the doctoral thesis

This research is structured as follows:

In the second part of the first chapter are analyzed the pillar tools of the concept of Industry 4.0 and identified those useful in the design and development of the platform.

The second chapter presents research on the current state of industrial cloud platforms, to highlight those shortcomings of existing solutions that lead to the need to implement the platform proposed in the thesis.

The third chapter is a study on virtual reality (concept, history, current stage) with an emphasis on those elements used in the platform to address some limitations identified in existing platforms. All three chapters theoretically substantiate the conception and development of the original solutions embedded in the platform made in the thesis starting from the results of the analysis summarized in the conclusions of each chapter.

Chapter four describes research on the design and development of an original IIoT platform, which includes an innovative method and an online system for encrypting, transmitting, storing and reading large volumes of data (National Patent Application, OSIM A 2017 00174) integrating collaborative virtual reality and its applications for coordinating material and information flows in the industry using a digital twin of manufacturing architectures. Also included are studies on expanding the scope of the virtual office platform, distance learning, conferences, trade fairs, entertainment and virtual television studios.

Chapter five presents the general conclusions, personal contributions, and prospects for further research.

Innovative methods for encrypting, transmitting, storing and reading data volumes large

Currently, due to increased automation and the transition to industry 4.0 There is worldwide demand for further development and implementation of systems for collection, archiving and interpretation of large data volumes (Big Data) in the Cloud, to ensure the integrity of data, their encryption for protection and the ability to access archived historical values for analysis and process optimization.

Historical data retrieval and archiving systems are currently known according to patents EP 2042958 A2, US 7853568 B2, US 7831317 B2, WO 2014001037 A2, (https://portal.unifiedpatents.com), but these have not been designed for cloud replication, archiving data locally. Also, to compress the volume of data, these methods use compression algorithms that can value the archived data.

"A picture is worth ten thousand words!"

(Chinese Proverb)

None of the methods, computer programs, or systems set forth in patents or literature contains a reference to the use of images as a medium for storing large volumes of historical data by creating and reading them. direct iterative at the pixel level.

In this context, the doctoral thesis developed an innovative method of archiving numerical data (integers, float) or text (UTF8) by using images or continuous video streams created from sequences of images generated over a period of time. This method implements a data encryption / decryption solution using pixel-level surface encryption / decryption based on a key image (symmetric encryption).

In addition, the generalization of the proposed method as an alternative data back-up solution for classical database systems for their encryption, archiving, transmission and restoration can also be done through an online system.

The proposed method (figure 1) is to create color images (24 bits, 16 million colors) whose pixels are generated based on numeric or alphanumeric values to store.

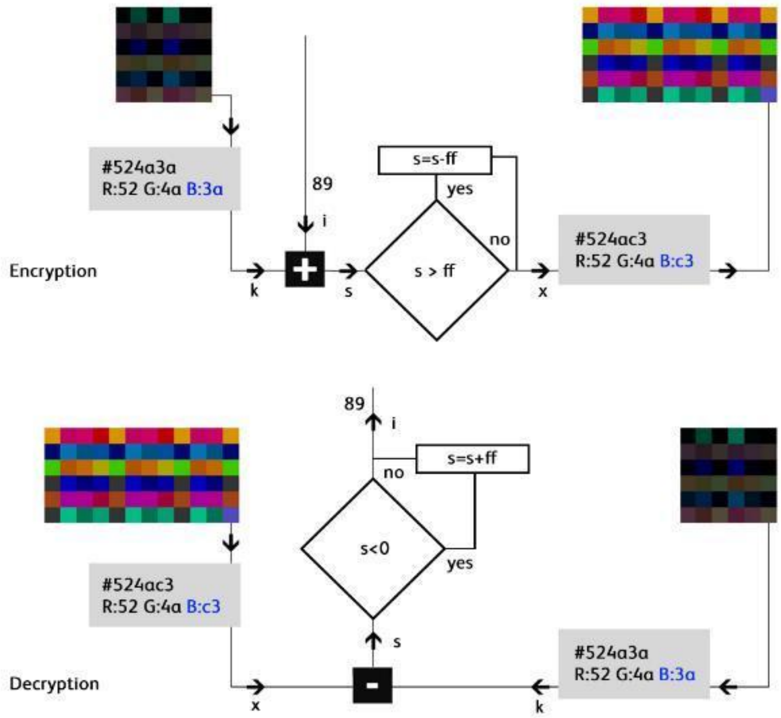

Figure 1. Encryption and Decryption

color of each pixel can be defined by the three-component values R, G and B with values between 0 and 255, respectively 0 and FF in hexadecimal. (Deac G. et al., 2019)

For encoding there are several variants of generating pixels depending on the type of values to be stored:

- In the case of positive integers between 0 and 16777215 encoding can be done directly by converting the number decimal to hexadecimal (e.g. 16777215 becomes FFFFFF), the 6-digit hexadecimal string explodes into three groups of two digits and each of this group is then converted to decimal (eg FF, becomes 255) and the pixel with RGB components is created (R = 255, G = 255 and B = 255, in this case a white pixel, corresponding to the maximum value that can be stored);

- In the case of positive and negative integers, the same encoding variant as above can be used by halving the maximum value to +/- 8388607, the numbers being encoded by summing the storage value by 8388607, decoding this value.
- In the case of float numbers (IEEE 754 double precision standard) (https://en.wikipedia.org/wiki/Double-precision_floating-point_format) they can be converted to hexadecimal values of 16 digits: 00.00.00.00.00.00.00.00, requiring thus a number of three pixels for storage (R1G1B1, R2G2B2 and R3G3, the last B3 component, no longer used). Thus, any float value with any number of decimals, positive or negative, can be archived using a group of three consecutive pixels. The image will have three times the number of pixels greater than the number of archived float values. The unused pixel may be available to encode the following values.

```
function floathex64 ($ num) {
   $ float64 = pack ("d", $ num);
   $ binarydata64 = unpack ('H *',
$ float64);
   return $ binarydata64 [1];
}
```

```
function hexfloat64 ($ num) {
   $ binarydata64 = pack ('H *', $
      num);
   $ float64 = unpack ("d", $
      binarydata64);
   return $ float64 [1];
      }
```

- In the case of alphanumeric values (UTF8) each alphanumeric character is converted to hexadecimal according to the UTF8 encoding table or its own table defined by the programmer (for example A becomes hex: 41, z becomes hex: 7a), so that each pixel will be able to store after the conversion from hexadecimal to decimal, a number of 3 alphanumeric characters, one for each component R, G, respectively B. The image will have the number of pixels equal to one third of the total number of characters.
- In the case of Boolean values (true, false), they can be stored three on each pixel (one on each R, G or B component), as values of 0 and FF respectively (255)

The image size can be defined according to the number values to be archived and of their type using the formula:

$$p = FLOOR\,(i / 3) + FLOOR\,(a / 3) + FLOOR\,(b / 3) + f * 3 \qquad (1)$$

p is the total number of pixels in the image generated

i - the number of integer values less than 16777215,

a - the number of alphanumeric characters,

b - the number of Boolean values,

f - the number of float values.

If a square aspect of the generated image is desired, the number of pixels will be equal to x and y and can be calculated with the formula:

$$px = py = FLOOR\ (SQRT\ (p)) \quad (2)$$

To encrypt data of any type, according to the encoding variants presented above, an encryption image (symmetric key) is used according to the presented method, to the values to be encoded by adding or subtracting values corresponding to the pixels in the generated encryption key image. Various encryption algorithms can be designed depending on the number and type of values being encoded and the size of the key encryption image (Figure 1).

The encryption key image can be generated uniquely, periodically or in the case of historical data series values, previously generated images can be used as encryption key images at predetermined times.

The online information transmission and storage system using the methods developed and presented above, which provides high data security at the time of transmission and storage and can replace traditional databases. The online system consists of the following modules (Figure 4.5) (Cotet C. E et al., 2020):

- (a) Data reading module that sequentially reads the data to be encoded either from a temporary local database or directly through an OPC-UA interface that ensures the protocol of direct communication with sensors and other process components;

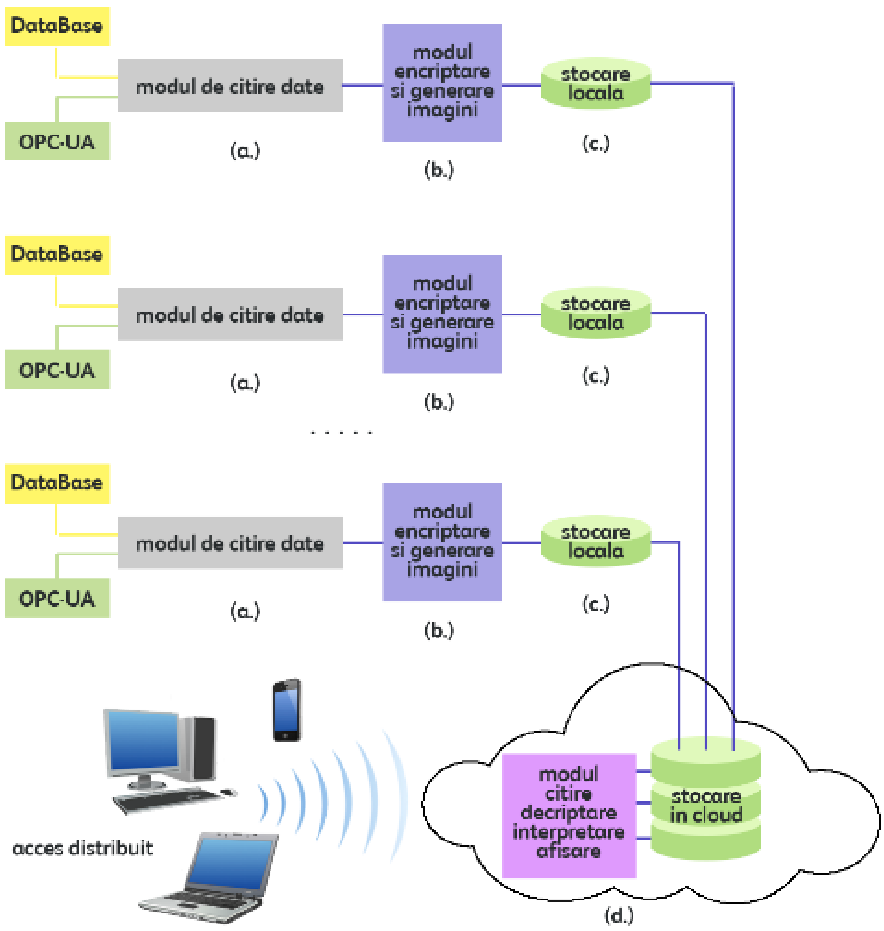

Figure 2. Block diagram of the online system

- (b) The data encoding and encryption module which sequentially receives the values returned by the data reading module and generates the archiving images. Depending on the number of distinct values to be archived and the type of data, this module calculates the pixel size for the archived images. For example, if a process generates 10,000 different float values at a rate of 50 frames per second, the module will generate 50 images with a size of 300x100 pixels every second.

These images are saved as a location identification prefix, followed by a numeric value equal to the time stamp at the time of generation (example: BU-1488545592358). The time stamp (Unix time, POSIX or epoch) is the number of milliseconds elapsed since January 1, 1970 at 00:00:00 UT;

- (c) The on-premises storage and replication module in the Cloud, which stores images generated in a locally defined buffer for storage even if there are problems connecting to the Cloud. Later, when filling this buffer, the new values can be overwritten over the previous ones. The generated images are also automatically sent to the Cloud for storage.

Based on the generated images, video streams with a preset duration, for example 60 minutes, can be encoded, which will contain all the images generated during this time. In the non-limiting example in the description, it represents 50 x 3600 = 180000 frames / hour at a resolution of 300x100 pixels.

For each sensor or monitored process element, the position of the pixel coordinates (in x, y coordinates) and the details about the respective element are known, these data being defined when configuring the system.

- (d) The module for reading, decrypting and displaying data, which includes software running in the Cloud. They can access, decrypt, decode, display and transmit various numerical or graphical reports based on a query protocol. For example, the query "Select the values of sensors 2 and 4 starting with 08.03.2017, time 13:55:00 for a period of 10 minutes" translates into the selection of pixels corresponding to the coordinates x: 4, 5, 6, respectively x: 10, 11, 12 and y: 1 (because they are float values, the encoding of the values is done using 3 consecutive pixels) from the series of images starting with BU-148898130000 to BU-148898190000. Pixel values are read sequentially, and the corresponding pixel values in the encryption key image are subtracted from these values. After decoding, the archived values are obtained (according to the method and variants presented above).

For a good organization of data, files can be defined in the storage environment in the Cloud, according to the model**:**

location / year / month / day / hour / minute.

Thus, the images will be stored in the last folders corresponding to the minutes. This archiving mode provides quick and easy access to data for replication on other storage media. Thus, if you want to process certain data locally, only the desired period is downloaded from the file structure.

Based on the images stored during a day, by running timed scripts (cron), separate images will be generated once a day for each property (sensor), containing all the values of that property for that day. Thus, there is a reduction in the number of stored images, with larger ones, distinct for each property, which ensures an even better data compression (approx. X10) and an increased speed when querying values. These will be stored in folders, according to the model:

location / year / month / day / property /

Also, using the same timed scripts, images can be generated containing hourly or full day aggregates for each property, which can then be used for long-term trend analysis and for analysis using machine learning or deep learning for predictive maintenance. They can be stored in folders, by model:

location / year / month / day / property / average

location / year / month / day / property / average

When PNG compression modules can be included in their generation, such as zopflipng, which is a software library for encoding PNG images by encoding them in DEFLATE, gzip and zlib formats (developed and distributed for free under Apache License version 2 by Google in 2013).

By using these optimization libraries, which are slower (80 to 100 times) than using the default DEFLATE format of PNG compression, it provides much better optimization by identifying pixels with the same color, creating an index, and replacing values with the corresponding indices. In an example implemented for the values of a sensor (float) for 7 days, with a sampling of 2 data / second by using zopflipng a compression of the PNG image from 4.3 Mb to 2.1 Mb was obtained, and as compression times, DEFLATE by default PNG 0.03 seconds, and zopflipng 2.8 seconds.

The system also allows real-time monitoring of the values that are archived, either directly by displaying the image or in another graphical form. If you want to compare in real time the values provided by sensors or other process tools with the reference values provided by an application of the virtual operating model (in English, twin) in the Cloud, the images generated by the technology flow are subtractive combined with the generated images. based on the reference values (standard), resulting in composite images, which ideally consist of black pixels. When deviations from certain process values occur, the corresponding pixels in the resulting images are colored according to these deviations. Thus, using extremely limited computing resources and hardware ensures real-time monitoring of a very large volume of data. By clicking with the mouse or touch on the screen in the area of the pixels with deviations from the image, details regarding the sensors and the absolute or deviation values are displayed.

This method has the following advantages:

- it allows the encryption and archiving of data having as storage medium the color images;
- image databases can be easily replicated by simple copying;

- significant compression of the volume of data stored and transmitted in the Cloud due to non-destructive PNG compression;

- decentralization of historical data generation and storage;

- real-time access to data, using reduced hardware resources;

- the possibility to access data for several processes running independently and at the same time in the Cloud;

- the possibility to process the data directly graphically by changing the color of the pixels, without the need to decode, process and re-encode them;

- the graphic form of archiving allows the compact and real-time visualization of the variation of the values by the simple display of the image;

- the possibility to compare in real time the process values with the standard ones by subtracting the two images generated based on them and displaying the resulting image.

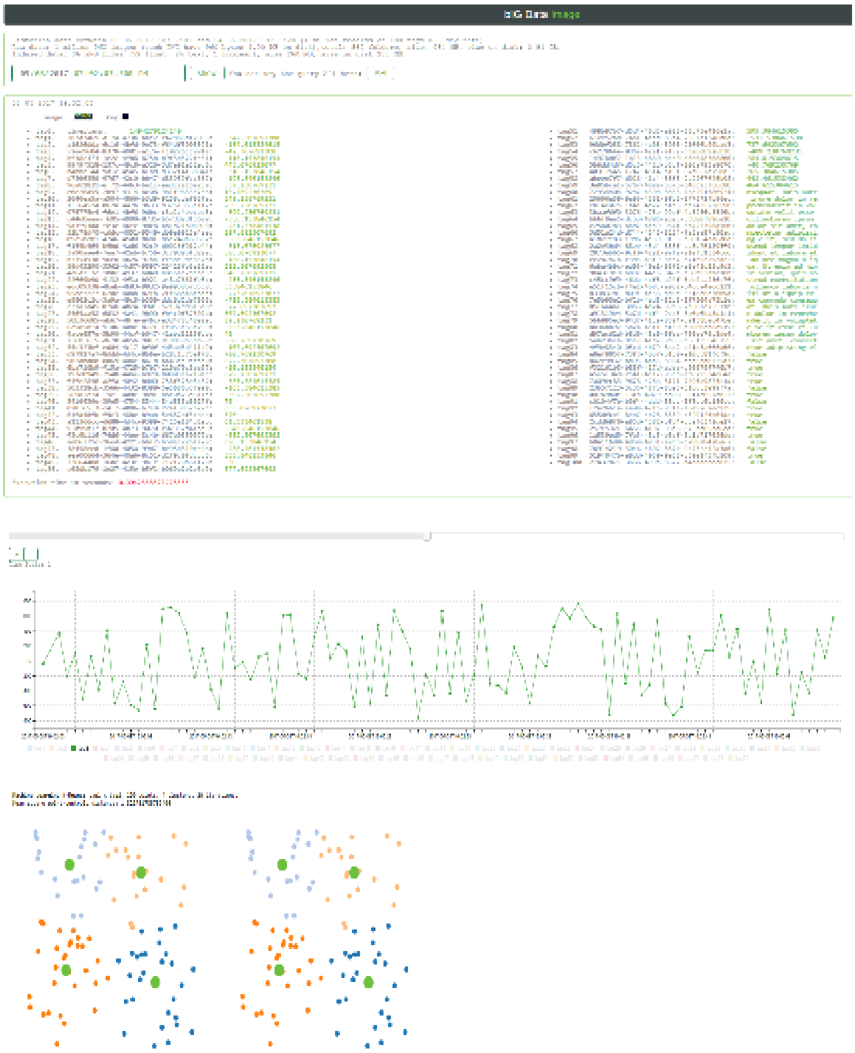

Figure 3. IIoT platform implemented based on the method

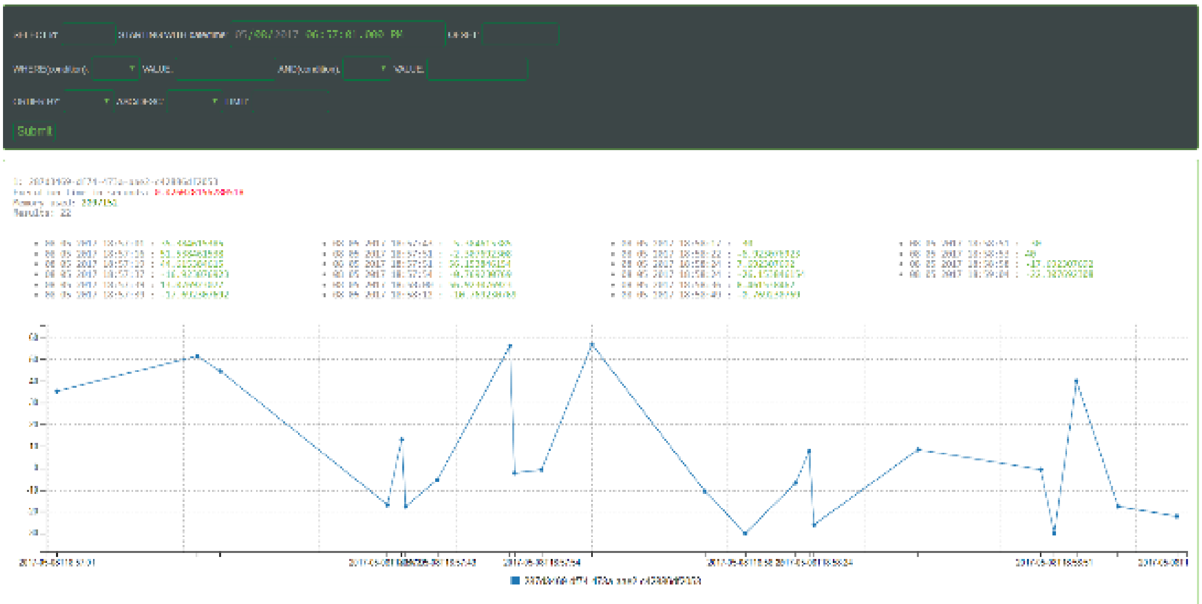

Figure 4 IIoT platform - pseudo-SQL API

Based on the proposed method, an IIoT platform was implemented, made on PHP HTML Java Script web technology (figure 3 and 4). The platform has two main screens: the historical data viewing screen and the image database query screen.

The historical data view screen contains a selector for date, hour, minute second, after selecting a historical moment, the values of all the properties of that moment are displayed numerically and graphically over a range of ± 50 records to visualize the historical variation of this data. The graph allows you to select the properties you want to display. A slider was also implemented that allows the selection of consecutive values on the time axis, incrementing the unit of sampling time (in this case, 0.5 seconds, because the frequency of telemetry data capture was set at 2 records per second).

Machine learning tools have been included in the same viewing screen: K-means and linear regression, which ensures a good view of the interval variation of historical data.

The image database query screen contains a data selection form that simulates SQL queries. The platform has an integrated SQL-query API (figure 4.7) that can be accessed by external applications, by calling an address of the form:

query.php? Id = 1 & s = 2017-05-08T18: 57: 01 & o = 2m10s & c = > & n = 33 & d = <& m = 58

& r = ASC & k = t & l = 100 & key = 0

where:

id is the property id,

s - start time yyyy-mm-ddThh: mm: ss,

o - offset (search period of historical data) can be expressed numerically (number of records) or as time hh: mm: ss, c - condition smaller higher, equal, different, etc.,

n - value to be compared by condition,

d - second condition,

m : comparative value of the second condition,

r - ordering of data (AUC or DESC),

k - t, v ordering principle (time or value of data),

l - limit (maximum number of values returned),

key - encryption key (0, 1…, n) data can be encrypted with different keys.

For the comparative tests of the proposed method with the current database systems we used historical data between 08 05 2017 18:57:01 and 14 05 2017 13:50:20 (1 million records of 100 distinct properties (59 float, 24 text, 17 Boolean) transmitted at a sampling rate of 0.5 sec).

Raw data: 1 million PNG images (each PNG has 960 bytes 4.00 KB on disk), a total of 562 files, size 954 MB, disk size 3.86 GB.

Indexed data: 86 PNG files (59 float, 24 text, 1 Boolean), size 260 MB, disk size **260 MB**.

Cassandra database: **20 GB.** PostgreSQL database: **18 GB.**

8agora – the collaborative virtual reality platform

The research carried out in the thesis materialized in the design and development of a collaborative VR platform that integrates a digital (twin) prototype that allows visualization, simulation and optimization of material and information flows in manufacturing architectures.

By developing middleware applications, the platform can collect, process and display real-time telemetry data, maintenance information, display libraries of technical documentation, synchronize and view material stocks in warehouses, synchronize machines and virtual and real manufacturing lines and allows remote control of machines and processes directly from the virtual environment.

This application was developed on a server-client architecture and can be used both in immersive VR mode, using HMD glasses and controllers, but also in desktop mode, on any computer or mobile device.

In the case of mobile devices (tablets, phones), but also in the case of using computers with limited hardware resources, there is the possibility of running the client application in the Cloud, on a GPU server, users accessing the application directly from a web browser through a control application remote with low latency and hardware acceleration (Deac GC et al., 2020).

8agora was developed from an open-source project: highfidelity.com with an architecture consisting of interconnected components that communicate with each other (figure 4.8):

- The client interface runs on the user's computer or remotely on a GPU server in the Cloud and allows connecting to and participating in live simulations.

● The server application is the main component that hosts content such as 3D models, scripts, files, audio communication module, and manages settings for audio attenuation, audio spatialization, codecs used for communication, zones, user permissions, maximum number of users competitors and backup policies.

● Global services allow users to connect and navigate to different locations in one domain, or to connect to other domains.

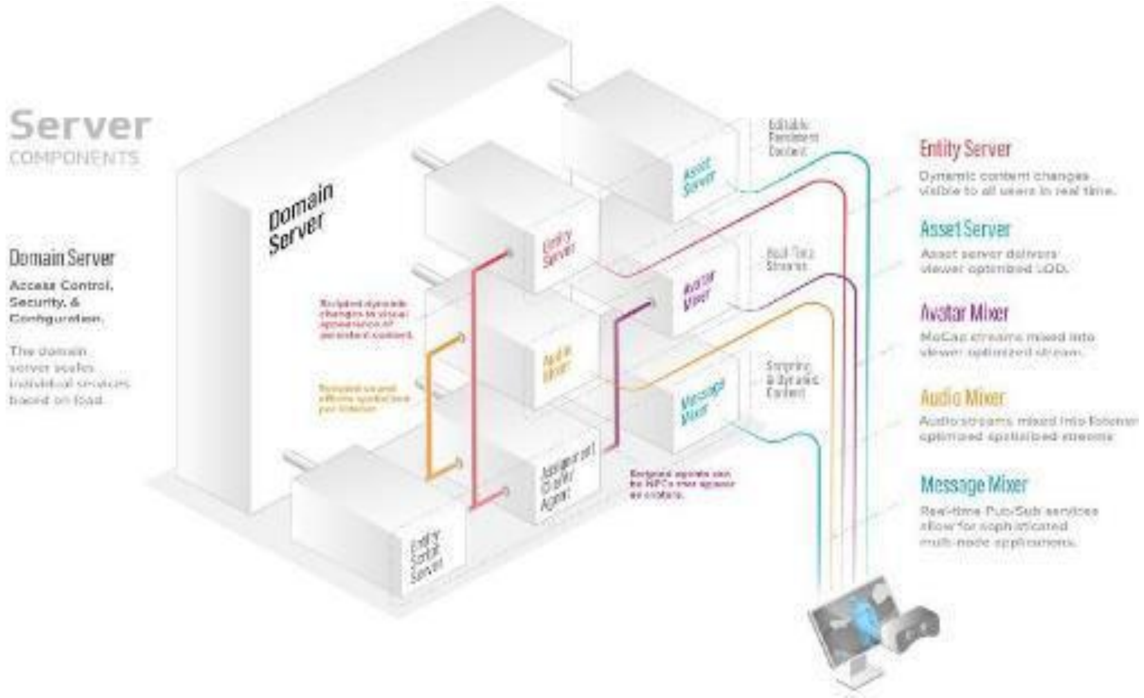

Figure 5. VR Application server components

In the server application, the domain server creates jobs for different client services and communicates both the IP addresses and ports for each client service to the connected user applications.

Customer service is responsible for various functionalities in the field. Work together and communicate directly with connected user applications.

IoT middleware application

For the integration of the digital twin model on the 8agora platform, the middleware application was created which includes the following modules: data acquisition and storage, animation driver, remote control and digital library (Deac GC et al., 2020).

a. Data Acquisition and Storage

Module This module consists of several UC OPC client applications that will read all values from sensors and process on time cycles with a predefined frequency (every second for example) and uses the encryption and encryption method of data using PNG images and their storage in the Cloud (according to the methods presented above).

b. Animation driver module (Deac GC et al., 2020).

The animation driver module was created to synchronize the movement of all cars, robots, AGVs (Automated Guided Vehicle), AMRs (Autonomous Mobile Robot), products and materials in the production lines. (Figure 4.13). There is a huge amount of real-time data in a factory that needs to be captured, transmitted, analyzed and processed to create a digital twin.

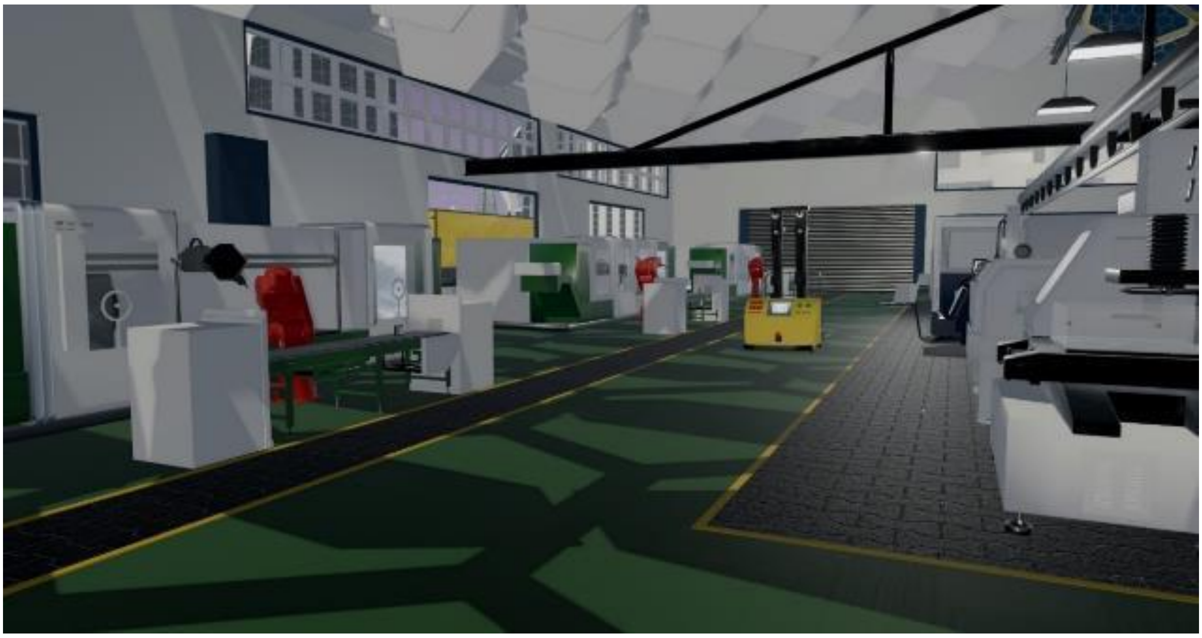

Figure 6. Implementation example for a digital twin using the 8agora platform

Sensor data can be collected from each machine: pressure, temperature, rotation, acceleration, vibration, operating status, states, alarms, errors, from AMR accelerometers, acceleration values on X, Y, Z, GPS positioning, battery level, current load, from automatic production lines, also a lot of data must be read. This complexity and large volume of data makes it impossible to create real-time animated models for the virtual factory based solely on telemetry values, as it would require extremely complex algorithms that would require high computing power and user experience. it would not be much improved.

With this in mind, a simplified model based on triggers was developed, and the telemetry data was used only for real-time visualization of the status of the selected component. An accurate 3D model with different animations was created for each machine for each work process. The speed of the animations can be adjusted to synchronize with the actual movement of the car.

A connection to the ERP database was used to display material stocks in warehouses so that the current stocks and the position of each component, product or raw material are read in real time. Using an expandable library of 3D models for components and materials and reading the position of each inventory piece, the shelves in the 3D simulation can be populated to be identical to those in the actual factory.

RFID readers can be easily used to synchronize products on production lines, but because not all current production lines have included monitoring of manufacturing processes based on this technology, a machine vision solution has been integrated that classifies and counts moving objects in real time and can be used for any implementation (Deac GC et al., 2017).

After analyzing the technical solutions available on the market at this time, the following system was designed, the diagram of which is shown in Figure 7.

The system consists of several video cameras placed at different points along the production line. The video signal from all cameras is processed by a video multiplexer, resulting in a single video stream with all images combined.

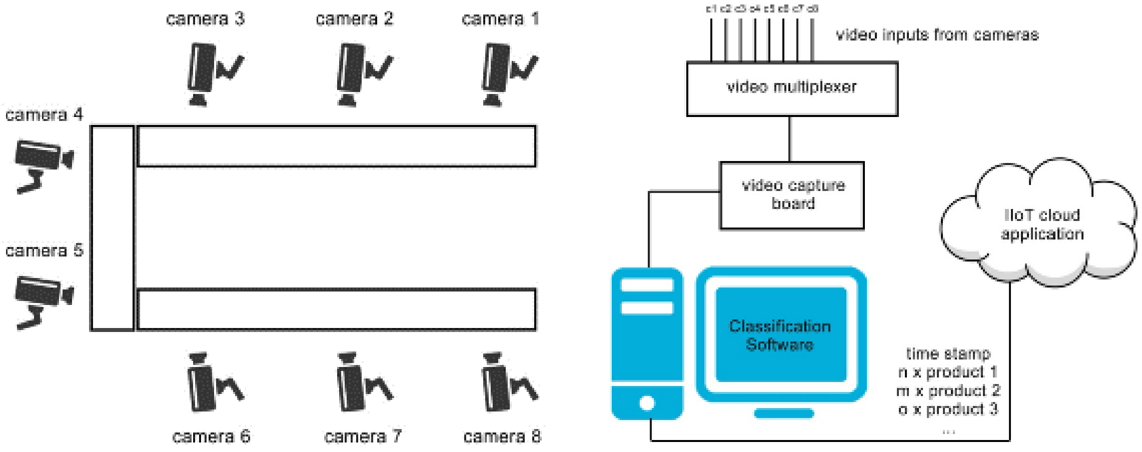

Figure 7. Vision system diagram

This video stream is captured by a video capture card and processed by the classification application running on the vision computer (Deac GC et al., 2017).

To obtain a real-time classification, YOLO9000 (Redmon, J. et al., 2016) compiled with CUDA support was used. The CUDA parallel architecture provides additional processing power at a low cost. Processing is done in real time; using an Nvidia GeForce RTX3090 video card, we can analyze the video stream at 60 frames per second. In the classification process, the combined image is magnified and followed.

The remote-control module has been implemented to facilitate real-time viewing of machines, access to the machine control panel to adjust parameters and trigger commands.

The remote-control module contains the following components:

- User authentication
- Remote desktop connection to the machine control panel
- Low latency live stream

The user login / password-based user authentication module allows the user to switch from view to remote panel control mode. Each user can only access remote controls on certain machines or processes.

The remote desktop connection module stream streams directly to the machine control panel screen and captures (after authentication) the user's actions and performs these actions on the machine's control panel.

This component uses the VNC protocol and is developed in Node.js, using web sockets and allows remote desktop sessions from Linux and Windows operating systems. The remote control window is displayed in a web browser entity within the VR platform.

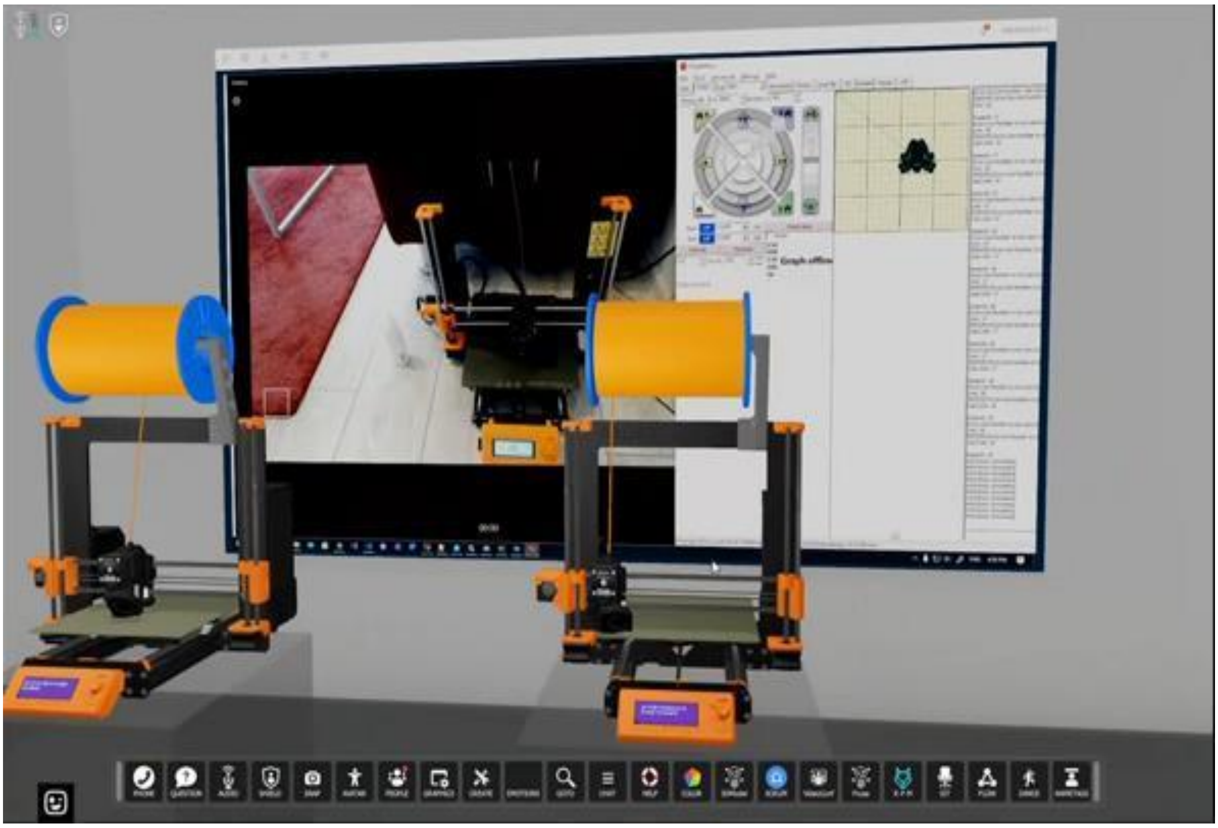

Figure 8 Live control and viewing screens

This approach, using the Remote Desktop connection, allows for easy deployment of remote sessions for all types of machines, with low latency (40-100 ms) (Figure 4.19), much better than using web services (800 ms), or CyberOPC (400 ms) (Bechtold, J., et al., 2014).

The low latency live streaming component uses video cameras and, based on a WebRTC implementation, provides remote viewing of the machine. This real-time view of the car is mandatory for remote control (figure 8). Demonstration, a stand with two Prusa MK3 3D printers was made. For the 3D printer on the left, a gcode interpreter has been created that allows loading and printing, and for the one on the right, a command interface that allows synchronization with a real printer.

Figure 9. Virtual assembly line

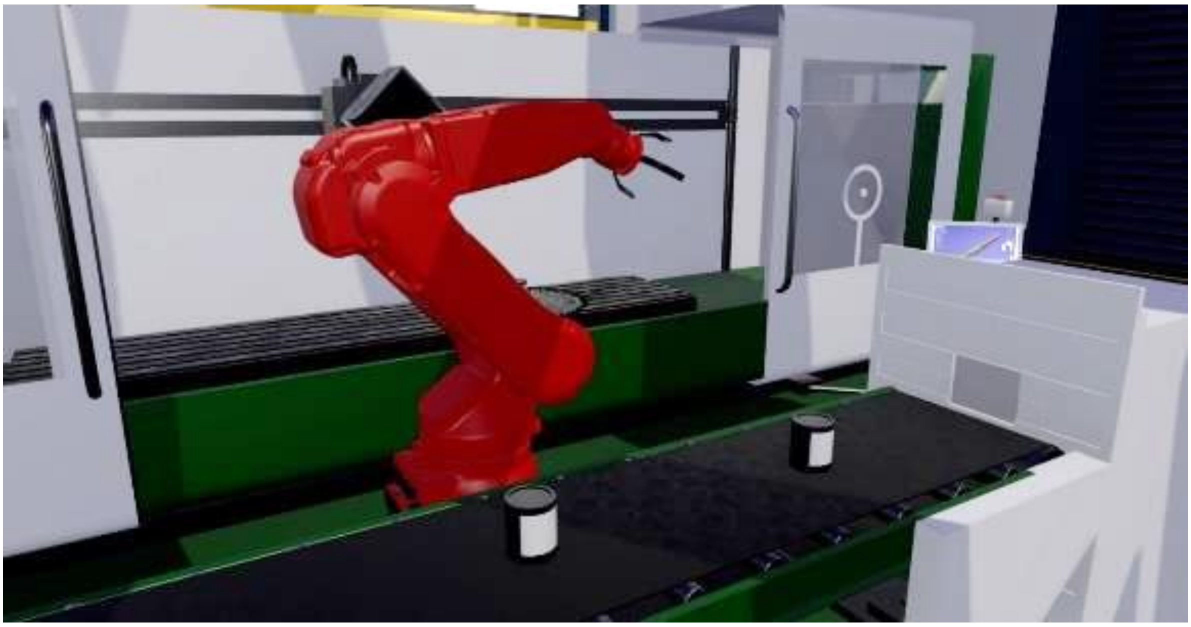

Figure 10. Machining center serviced by an articulated arm industrial robot

Several areas of machine components have been implemented on 3D machine models, and when a user clicks on one of these areas with his controller, he can display sensor telemetry data, maintenance information (a predictive maintenance Cloud application can also be implemented to see the remaining operating hours for each component) (Figure 9) (Deac CN et al., 2019), (Deac CN et al., 2020), (Deac CN et al., 2019) al., 2021).

A technical library has also been included and all users can access real-time technical information on machines and processes by clicking on car brand logo (Deac CN et al., 2017).

Extending the scope of the platform

Although the 8agora platform has been developed for use in IIoT implementations as a collaborative visualization interface for the digital twin, due to its architecture and functionality, the areas of use can be multiple. Thus, the uses can be easily extended by implementing dedicated simulations for e-Learning, virtual office, conferences, team building, virtual exhibitions and fairs, entertainment (clubs, cinemas, art exhibitions, virtual theaters, malls and virtual stores, virtual television studios), the only limit being the imagination (https://8agora.com).

Personal contributions

All the contributions have been structured in accordance with the objectives set out in the first chapter of this paper. Thus, the main contribution of the research carried out in the thesis is the design and development of a collaborative platform that uses virtual reality to allow visualization, simulation and optimization of material and information flows in manufacturing architectures. The material and information flow coordination platform developed in the thesis presents a series of personal contributions, which differentiate it from the existing platforms on the market, advantages conferred by the designed and integrated components both as an integrated product and by the original solutions they incorporate. Thus, the main personal contributions included in the realization of the platform are the following.

1. A series of theoretical research have been carried out on the concept of Industry 4.0. The purpose of this research was to select industry 4.0 pillar solutions to be incorporated into the platform design (Chapter 1).

2. A series of research have been carried out on the current state of the industry Cloud platforms. The purpose of this research was to identify the limitations of these platforms which substantiated the need for the proposed platform. Existing limitations have been the basis for innovative solutions embedded in the design of the platform (Chapter 2), as follows:

- development of a method for transmitting and storing large data, using PNG images as a storage medium.
- development of a message-based middleware application for synchronizing virtual machines.
- development of a vision system for monitoring production lines.

3. A series of theoretical research have been carried out on virtual and augmented reality. The purpose of this research was to select solutions to be incorporated into the platform design (Chapter 3) by addressing some of the limitations of existing platforms identified in Chapter 2. These solutions were based on the following personal contributions: the

- design and development of a collaborative virtual reality platform. as a development environment.
- designing integrated applications for this platform.
- extending the scope of the platform.

Among the personal contributions listed above, we consider it necessary to detail the concept and develop a method for transmitting and storing large data, using PNG images as a storage medium due to the possibilities of extending the applicability.

Thus, the online method and system (protected by patent application) for encrypting, transmitting, storing, and reading large volumes of data includes its own contributions:

- it allows encryption and archiving of data based on color image storage.
- ensures good data security by using encryption methods using a symmetric image key.
- image databases can be easily replicated by simple copying.
- significantly compresses the volume of data stored and transmitted in the Cloud due to non-destructive PNG compression (storage space about 100 times smaller compared to current databases).
- decentralizes the generation and storage of historical data.
- allows real-time access to data using limited hardware resources.
- provides access to data for multiple processes running independently and at the same time in the Cloud.
- offers the possibility to process data directly graphically, by changing the color of the pixels, without the need to decode, process and re-encode them.
- the graphic form of archiving allows the compact and real-time visualization of the variation of the values by the simple display of the image.
- offers the possibility to compare in real time the process values with the standard ones by subtracting the two images generated based on them and displaying the resulting image.

In conclusion, we can say that the main objective of the thesis was achieved by integrating the solutions that were secondary objectives. Thus, by integrating the data encoding method using PNG images and the simplified trigger-based model into the data acquisition and storage module, by developing the animation driver module and the remote-control module, and by using Industry 4.0 pillar technologies the conceptual synthesis and development of a virtual reality platform (8agora) that integrates the function of coordinating material and information flows in the manufacturing architectures was successful. The platform allows a natural viewing of the digital twin by several users simultaneously, who can communicate and interact with each other and access in real time information about production lines such as telemetry data, process data, maintenance data, technical libraries etc. and order real machines and processes directly from the virtual environment.

The 8agora platform, thanks to its architecture, ease of integration and development based on the import of 3d models in FBX, OBJ and GLTF format, the API library exposed in java script and integrated communication and multimedia tools is a modern, immersive interface for viewing twin digital and is an open platform for the development of complementary collaborative applications, such as: e-Learning, virtual office, conferences, team building, virtual exhibitions and trade fairs, entertainment (clubs, cinemas, art exhibitions, virtual theaters, virtual shops and stores, virtual television studios), etc. https://8agora.com

Prospects for further research

Following the synthesis of the general conclusions, a series of perspectives for further research emerged, as follows:

- implementations of the solution presented for the management of material and information flows of manufacturing through the use of the twin digital in industry;

- development and improvement of the 8agora platform with new applications;

- integration of the IIoT VR platform with flow simulators (Witness, FlexSim, Simcad Pro, etc.);

- designing and making dedicated hardware equipment for running the client application;

- designing and building Cloud equipment for the client application and live streaming to users;

- implementation of the 8agora platform as a support for distance learning at the University Politehnica of Bucharest.

- 8agora spin-off for SAAS services (software as a service) and customized for collaborative VR applications https://8agora.com - based on the business plan developed and awarded within the "Be Antreprenor" doctoral program (https: // 8agora .com / 8agora-business-plan.pdf).

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