Constructing the measuring system in industry 4.0 concept

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Abstract: The context of global changes in world trends makes the development for the target architecture of the digital platform and the detail of these solutions relevant, this is due to the growing problems for digitizing complex heterogeneous industrial systems. The objective is to create the measurement system in Industry 4.0 concept. The concept should contain the requirements for the measurement system, the procedure for constructing the measuring system, the state of tracking of an underlying asset attributes (oil product) at all stages of its life cycle. The authors proposed the measurement system in Industry 4.0 concept, which is aimed at the optimal construction of the measuring system of the state attributes of the main asset (petroleum product) and the optimal equipment condition. The concept that has been developed can be used in petrochemical processing and oil and gas industry.

1. Introduction
A rapidly developing industrial paradigm "Industry 4.0" lies at the heart of the global digital transformation of production systems. According to I4.0, the digital transformation is based on the digital twin of the production system [8-10] (Digital Twin Production Systems, DTPS). The conception DT is developing rapidly in the conceptual representation of [8-11] due to changes in the point of view on manufacturing, technical and organizational systems.

According to the object representation of systems and their components [12], it can be assumed that DT is an abstract entity, reflecting the required properties of a physical entity and its behavior through communication with other entities.

This representation makes it possible to separate the behavior as an entity, to analyze it and manage it. As for any system, its subsystems and components, the conception of its life cycle is applicable [13], which necessarily has all the stages common to any system as those of analysis and design, implementation (production), operation, development and decommissioning. DT is an abstract entity that is a reflection of the physical, and should be considered in the context of physical entity life cycle.

The most researched type of DT is the twin prototypes (Digital Twin Prototype, DTP), which are created at the stage of analysis and design within the framework of developing implementation (manufacturing) of the product. Then the products develop and begin to be actively processed and used as digital twin copies (Digital Twin Instance, DTI), which have different properties, values of properties and behavior that are used in simulation and other models. However, integration and usage of the CSD in the subsequent stages of the life cycle (Digital Twin Aggregate, DTA) remain a significant and unsolved problem [8-11,14], despite understanding importance and the trend of solution development I4.0.

Gartner experts note that CSD is the basis of DT assets, subject to its use and providing DT support at all stages of the life cycle of a physical product system (product-service); "The complexity of digital twins will vary based on the use case, the vertical industry and the business objective"; "Digital twins..."
drive the business impact of the Internet of Things (IoT) by offering a powerful way to monitor and control assets and processes" [15].

There are many well-known technical software solutions for working with DT at the analysis and design stage, which have powerful analytical tools. These solutions may work locally or the results of their use may be integrated into other design systems. The main problem is to ensure mature interoperability [16] and quality [17] of the newly obtained data and information based on them, at all stages of the life cycle, both physical and digital assets for the formation, evaluation and adoption managerial engineering and technical solutions, including the creation of an automated control system for equipment and technological process.

2. Problem statement
In this paper, we consider a production system, the main mission of which is oil refining, therefore, the main assets are oil product [18], which determines the value of a company in the oil and gas industry [19].

The basis for the detailed design of the structural solution is a digital 3D model of the Digital Platform concept of digital production architecture, which has oil production in its life cycle [6], and its formal presentation [19].

We enhance the definition of DT [19], taking into account the development of DT throughout the life cycle (Digital Thread): DT is "integrated multiphysical, multi-scale, probabilistic modeling of the embedded system provided by Digital Thread, which uses the best available models, information about sensors and inputs for mirroring and predicting actions performance over the lifetime of its corresponding physical twin" [20].

The paper [21] proposed the concept of object-oriented architecture of the logics of the effective management of production activities for the oil refinery in the integrated system of corporate governance VICs. The concept was developed on the basis of the analysis of current international standards, declaring the integration in the «Internet of Things» industrial enterprise management systems and advanced industry standards [22-26].

When generating a DT production system, the actual state of the values is determined on the basis of analysis of real time data obtained from the sensors.

The general idea of DT subsystems and their elements has a network structure, which depends on the production process of oil products.

The technological process of a continuous type, which has elements of batch processes, may have a number of parallel and / or inverse processing cycles. The nodes of this structure are the places of generating useful information and do not coincide for the system components. A request for a managerial decision defines the use of the generated information.

The purpose of the (production) process (or its segment, operation, segment of operation) is to obtain oil product(s) (by-products) with specified intermediate or final properties (in the value chain) with the maximum possible effective performance.

The following two problems need to be solved:
- assets but not sensors simulation;
- using data to provide meaningful ideas for generating control action in order to achieve the desired assets status throughout the life cycle.

Abbreviated mnemonic names, including indices are intentionally used for the purpose of clear presentation of concepts to describe the multifaceted mental model.

To overcome the complexity of presenting the structure of the system representing the system of SoS & G systems [27–29], we will distinguish some systems while observing the basic condition for ensuring the emergence of a business system.

Will take: $S_{el}^{ac}$ – the system of elements that determine the state of the asset "oil product" from the point of view of extracting useful information about it and for the formation and decision-making which depends on the life of the asset and the hierarchy of its management level:
where:

- \( oI \) – name of oil product;
- \( atr_{oi} \) – set of properties and states of their values that define \( oI \);
- \( R \) – relationships (as followed from the definition of the system in an object-oriented paradigm), which are determined by logic, connecting \( oI \) with certain properties and their values \( atr_{oi} \), from the point of view of element \( Ac \), having the right and ability to set a goal \( G \) for making a decision and making an appropriate decision for its achievement;
- \( Ac \) – can be any element ("not human") with the right formation and management decision at the stage of oil product life cycle or its segment.

A similar definition of supporting systems of asset-resources \( S^{oI} \) ("role equipment" used in the production process segment) and \( S^{sT} \) (personnel employed in the production process segment), as well as the space of defining elements, are given in the works describing the general Concept of global digitization of business systems [19, 21].

This work has an emphasis on the life cycle of oil product at the stage of its production:

\[
S^{oi} = \{oI, atr_{oi}, R, G, Ac\},
\]

where:

- \( T \) – a set of segments of the oil product manufacturing process;
- \( K \) – the number of segments;
- \( T_k \) – the minimum functional logical grouping of control objects – workflow unit that performs a mission at the functional level – changes in the oil product condition in accordance with the technology.

The segment can be identified by a set of properties (including properties which determine the moment):

\[
T_k = \{atr^{k}_{1}, atr^{k}_{2}, ..., atr^{k}_{N_r}\},
\]

where \( N_r \) is the number of segment properties.

3. Theory

According to the operating logic and functional concept (organization process concept), the life cycle of the main asset and resource assets is deployed on the ox axis, subject to the mission and value added. The part of the life cycle corresponding to its implementation stage, including the stages of analysis and design and production, is presented in Figure 1.

OX axis is used to detect and identify information objects-asset (Information Asset) (main and supporting), forming a complex network multilayer structure of the production system - SPlant.

SPlant system assets can be considered at different stages of their life cycle (concept, Implementation (manufacturing), operation and maintenance, disposal).

In order to effectively manage the life cycle of the system \( S^{oi} \) at its production stage (implementation, including analysis and design) let us define the meta-system \( S^{ControlPlant} \), which should effectively manage \( S^{Plant} \) during the operation of the asset-resource systems \( S^{oI} \) and \( S^{sT} \).

According to I4.0, special-purpose subsystems or services providing specific services should be integrated into \( S^{Plant} \) and \( S^{ControlPlant} \), respectively. It depends on the purpose and level of decision-making.

Such a representation allows one to “glue” digital twins of systems (subsystems, services) on the general representation of \( R \), to provide \( G \) depending on \( As \), and also to provide logical belonging to \( T_k \).

The effectiveness of management of the meta-system SControlPlant will be to manage the cost of the guarantees required by state SoI main asset of the system and the value of their software assets resources.
For generating the DT that contains data objects, assets, the following general comments are to be made:

- the principles of data formation that are important for gaining knowledge in order to effectively control the execution of the mission should be laid;
- measuring the change of states of interacting systems, subsystems, and elements should be determined by the processes influencing the added value of the underlying asset (process (segment operation, operation segment). As the basis for determining the coordinates industry-specific measurement models can be used (monitoring, control and diagnostics) established for oil refining processes and re-emerging as a result of obtaining new knowledge through the use of DT systems and their interaction;
- the required state of property values must be guaranteed in accordance with the policy of ensuring the quality of oil products, all processes of certification of oil products must be provided;
- the required value of the state properties of the equipment must provide the required state of oil product properties.

Figure 1. The life cycle of oil products at the stage of its implementation.

Taking into account that "the purpose of the measurement process is to collect, analyze and make official reports on objective data and information to maintain effective management and demonstrate the quality of products, services and processes", we will accept the basis that the content of the 0X axis coordinates occurs on the basis of implemented processes for measuring the state of previously
designated systems (information to be managed is determined, informational grants are determined, information is received, delivered, formed, stored, verified, destroyed if necessary).

We introduce the following notation: $S^{\text{Metr}}$ is a measuring system, $S^{\text{ControlMetr}}$ is a control system of measuring system changes.

The measuring system must take into account the repetition of measurements, and the use of indirect methods for measuring the actual state of oil properties and equipment properties.

4. Results of the experiments
The concept of "Constructing the measurement system in Industry 4.0" refers to the simulation of the digital twin measuring system of values of the state oil product properties in accordance $S^{\text{olMetr}}$ with the technological requirements:

\[
S^{\text{olMetr}} = \left\{ oI, atr_{ij}^{\text{olM}}, M[atr_{ij}^{\text{olM}}], U[atr_{ij}^{\text{olM}}], R, G, Ac \right\},
\]  

where:

- \( atr_{ij}^{\text{olM}} = \{ [{atr_{ij}^{\text{olM}}}, {atr_{i2}^{\text{olM}}}, \ldots, {atr_{in}^{\text{olM}}}] \} \) - is a set of simulated desired properties of oil product \((i = 1, n_{ol})\);
- \( atr_{ij}^{\text{olM}} = \{ [{atr_{ij}^{\text{olM}}}, {atr_{i2}^{\text{olM}}}, \ldots, {atr_{in}^{\text{olM}}}] \} \) - is a simulated set of multiple state measurements of a specific property \((j = 1, m_{i})\);
- \( m_{i} \) – the number of measurements of the \(i\)-th oil product properties states, provided that the time between the first and the \(m_{i}\) measurement is neglected to estimate the expected value of the measured value;
- \( M[atr_{ij}^{\text{olM}}] \) – the estimation of the mathematical expectation of the measured value of the \(i\)-th property state of the oil product based on the simulated digital twin of the measuring system;
- \( U[atr_{ij}^{\text{olM}}] \) – the indeterminacy of the measured value of the state of the \(i\)-th property of the oil product based on the simulated digital twin of the measuring system.

As well as modeling of the DT measuring system $S^{\text{olMetrF}}$, which is based on the actual values of the states of the properties of the oil product obtained from the sensors:

\[
S^{\text{olMetrF}} = \left\{ oI, atr_{ij}^{\text{olF}}, M[atr_{ij}^{\text{olF}}], U[atr_{ij}^{\text{olF}}], R, G, Ac \right\},
\]  

where:

- \( atr_{ij}^{\text{olF}} = \{ [{atr_{ij}^{\text{olF}}}, {atr_{i2}^{\text{olF}}}, \ldots, {atr_{in}^{\text{olF}}}] \} \) - is a set of actual measured properties of oil products \((i = 1, n_{ol})\);
- \( atr_{ij}^{\text{olF}} = \{ [{atr_{ij}^{\text{olF}}}, {atr_{i2}^{\text{olF}}}, \ldots, {atr_{in}^{\text{olF}}}] \} \) - is a set of multiple measurements of the values of a specific state of the oil product properties;
- \( m_{i} \) – the number of measurements of the \(i\)-th property state of the oil product, provided that the time between the first and \(m_{i}\) measurement is neglected to estimate the expectation of the measured value;
- \( M[atr_{ij}^{\text{olF}}] \) - the estimation of the mathematical expectation of the measured value of the \(i\)-th property state of the oil product;
- \( U[atr_{ij}^{\text{olF}}] \) – the indeterminacy of the measured value of the \(i\)-th property state of the oil product.
Developing $S^{\text{Metr}}$ for the assessment of all $S^{\text{Plant}}$ one should take into account that the properties and their values at the stage of life cycle $S^{\text{Sol}}$ depend on the properties and their values $S^{\text{SeQ}}$ during operation. Accordingly, the converse is true - the $S^{\text{Sol}}$ properties and their values determine the requirements for the properties and their $S^{\text{SeQ}}$ values.

It should be taken into account that when developing the $S^{\text{ControlMetr}}$ change management system for the $S^{\text{Metr}}$ system, the life cycle model of the $S^{\text{Sol}}$ system is incremental (Figure 2).

The last statement defines the main differences of constructing the measurement system in Industry 3.0, based on the complex automation of the analysis and design processes, from constructing the measurement system in Industry 4.0. It includes the processes of measurement system in Industry 3.0, as well as the processes of the stages of operation and utilization, which are associated with the end user and the prediction of changes in the estimation of the properties of the petroleum product and their values by stakeholders.

The application of the proposed concept in the automated control of equipment that manufactures an oil product should provide for the installation of measuring sensors under the following conditions:

- the optimal number of measuring sensors on the condition of minimizing the number of sensors;
- the optimal location of the measuring sensors on the condition of minimizing measurement uncertainty;
- the ability to take into account the modernization of the equipment used to create the measuring system;
- the presence of additional (backup) measuring sensors required for the following functions:
  - self-diagnosis of measuring sensors in the measuring system;

**Figure 2.** Development of the interaction logic of the life cycle processes of the system of the main asset $S^{\text{Sol}}$ and the supporting system of the asset – resource $S^{\text{SeQ}}$ in the Concept Metrology 4.0.
• working out the program for setting the characteristics of the main equipment in the production of oil products;
• setting the accuracy of the readings of the measuring sensors, due to indirect measurements of the characteristics of the equipment;
• redundancy of measuring sensors when it is impossible to take reliable readings from them;
• providing analysis of the readings of the measuring sensors to search for and identify patterns of changes in the characteristics of the equipment used and, accordingly, equipment repair as.

Such a system of automated equipment control, which is developed on the basis of the measuring system, has the ability to control the equipment as it is and the ability to adjust the technological process to the state of the equipment.

5. Results discussion
The basic aspects that influence the formation of the Concept are:
• properties of the $S^d$ system and their values, which determine the state of the $S^{blear}$ system at the current time, depend on previous estimates of the states of the properties of the $S^d$ system;
• properties of the $S^d$ system and their values that determine the state of the $S^{blear}$ system at the current time depend on the required assessment of the state of the $S^d$ current properties and on future, predictable estimates taking into account the risks of changes in the assessment, and, consequently, the likely changes in the significance of the $S^d$ properties;
• the target measurement uncertainty of the property values of the $S^d$ system depends on the degree of feasibility of implementing adaptive control of the measuring system $S^{ControlMetr}$;
• optimization of the property values of the $S^{blear}$ system depends on the requirements imposed by interested parties to $S^d$, which may change;
• the formulation of problems of optimizing the property values that determine the state of $S^{blear}$ should be based on the solution of the problem of determining the optimal properties $S^d$;
• information service $S^{ControlMetr}$ should provide self-diagnostics of measuring instruments system, measuring instruments, backing up the measuring instruments system, measuring instruments, managing the metrological characteristics of measuring instruments;
• implementation of process control on the equipment, taking into account its state and interaction with each other, especially when using backup equipment.

6. Findings and conclusion
Global digitization of production systems forms a digital twin of control objects.

In accordance with the policy of ensuring the quality of oil products, there must be a guaranteed, including an adaptive measurement system, the required state of the values of the oil product properties, which is the altered state of the “raw materials” in the chain of production processes, or their segments, which are provided by associated resources.

In accordance with the concept proposed by the authors, it is necessary to solve the following problems when creating a measurement system:
• develop an intelligent information system for identification and unification of information objects interacting within the boundaries of a process (process segment, operation, operation segment) that are to be “glued together” taking into account full readiness of requirements for interoperability of the DT model system and their elements, and readiness to ensure the required level of integrity – intellectual service for the formation of requirements for measurement models;
• develop an intelligent change management system of the measuring system – an intelligent service for managing the system of changes in measurement models, for managing changes in accordance with changes in the logic of forming a management decision;
• develop the logic of transfer, placement, storage, search of metrological data – conditionally selected functional metrological domain;
• develop an automated monitoring system that allows you to track the status of each piece of equipment used in the process, taking into account the measurement information from all equipment.

The tasks of the intelligent service of controlling the measuring system in the creating measurement system in Industry 4.0 (for an oil production system) require the following solutions:
• refinement of models for measuring the states of properties and their values as a result of the integrated implementation of the technological (production) process (operation, segment of operation);
• determine the optimal (rational, due to the added value of the asset) the number of measuring instruments and the optimal (rational) layout of measuring instruments;
• determine the requirements for metrological characteristics of measuring instruments;
• develop a management system for a system of measuring instruments, measuring instruments themselves, metrological characteristics of measuring instruments.

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8. References
[1] Industrial Internet Consortium (IIC): Industrial Internet of Things, Volume G1: Reference Architecture, version 1.80, 2017-January-31, retrieved http://www.iiconsortium.org/IIRA.htm
[2] VDI/VDE/ZVEI, “GMA Status Report: Reference Architecture Model Industry 4.0 (RAMI 4.0)” (2015) https://www.zvei.org/en/press-media/publications/gma-status-report-reference-architecture-model-industrie-40-rami-40/
[3] Internet of Things – Architecture: Terminology, VDI/VDE Innovation+Technik GmbH retrieved https://web.archive.org/web/20160104220408/
[4] Industrial Internet Reference Architecture IIC:PUBLIC:G1:V1.07:PB:20150601 2015-06-04 Version 1.7 retrieved https://www.iiconsortium.org/IIRA-1-7-ajs.pdf
[5] Smart Grid Coordination Group – Smart Grid Reference Architecture, CEN-CENELEC-ETSI (2012). version 1.80, 2012- November, retrieved https://ec.europa.eu/energy/sites/ener/files/documents/xpert_group1_reference_architecture.pdf
[6] Andiev E Yu, Kapelyuhovskiy A A and Kapelyuhovskaya A A 2017 New approaches to digital transformation of petrochemical production AIP Conference Proceedings 1876
[7] Löwen Ulrich, Braune Annerose, Diesner Markus, Huettemann Guido, Klein Matthias, Thron, Mario, Manger Tobias and Okon Michael 2016 Industrie 4.0 Components–Modeling Examples
[8] Glaessgen E H, Stargel D 2012 The digital twin paradigm for future NASA and us air force vehicles 53rd Struct. Dyn. Mater. Conf. Special Session: Digital Twin, Honolulu, HI, US, pp. 1–14,
[9] CECS Technical Report CECS TR#17-07 November 27, 2017 Digital Twin of Manufacturing Systems http://cecs.uci.edu/files/2018/03/cecs_tech.pdf
[10] Wan J Canedo J Al Faruque M A 2015 Cyber–physical codesign at the functional level for multidomain automotive systems IEEE Systems Journal 11 pp 2949 - 2959
[11] Uhlemann T, Lehmann C and Steinhilper R 2017 The Digital Twin: Realizing the Cyber-Physical Production System for Industry 4.0 Procedia CIRP 61 335-340 DOI: 10.1016/j.procir.2016.11.152.
[12] Shlaer S Mellor S J 1988 Object-Oriented Systems Analysis: Modeling the World in Data (Prentice Hall, Englewood Cliffs, N.J.)
[13] ISO/IEC/IEEE 15288:2015 Systems and software engineering – System life cycle processes. https://www.iso.org/standard/63711.html/
[14] Grieves M Origins of the Digital Twin Concept. retrieved https://www.researchgate.net/publication/307509727_Origins_of_the_Digital_Twin_Concept
[15] Christy P Prepare for the Impact of Digital Twins g 2017 Gartner
[16] ISO 11354-2:2015 Advanced automation technologies and their applications – Requirements for establishing manufacturing enterprise process interoperability – Part 2: Maturity model for assessing enterprise interoperability retrieved. https://www.iso.org/standard/57019.html
[17] ISO 8000-2:2018 Data quality – Part 2: Vocabulary retrieved 2018-11 https://www.iso.org/ru/standard/76563.html
[18] Andieva E Yu Tolkacheva E V 2018 Development of methodological basis I4.0 for production systems of oil refining industry Oil and Gas Studies. 4 26-35.
[19] Digital Twins: The Bridge Between Industrial Assets and the Digital World https://www.ge.com/digital/blog/digital-twins-bridge-between-industrial-assets-and-digital-world
[20] Andieva E Yu, Mikhailov V A 2018 Digital transformation of integrated management systems of an oil refining enterprise production activity Automation, telemeshanzation and communication in oil industry 10 26-35
[21] IEC 62264-1:2013 Enterprise-control system integration – Part 1: Models and terminology URL: https://www.iso.org/standard/57308.html.
[22] IEC 62264-2:2015 Enterprise-control system integration – Part 2: Objects and attributes for enterprise-control system integration URL: https://www.iso.org/standard/57310.html
[23] ANSI/ISA-88.01-2010 Batch Control Part 1: Models and terminology
[24] ISO 16300-1:2018 Automation systems and integration - Interoperability of capability units for manufacturing application solutions – Part 1: Interoperability criteria of capability units per application requirements
[25] ISO/IEC CD 30141:20160910(E) Information technology – Internet of Things Reference Architecture (IoT RA). CD stage World Wide Web Consortium (W3C) https://www.w3.org/WoT/IG/wiki/images/9/9a/10N0536_CD_text_of_ISO_IEC_30141.pdf.
[26] SEBoK v. 1.9.1, released 16 October 2018 https://www.sebokwiki.org/wiki/System_of_Systems_(SoS)_glossary
[27] Jamshidi M 2008 Systems of systems engineering: principles and applications CRC Press, New York 37–70
[28] Jaradat R M, Adams F Abutabenjeh and S Keating C 2017 The Complementary Perspective of System of Systems in Collaboration, Integration, and Logistics: A Value-Chain Based Paradigm of Supply Chain Management Systems, 5
[29] Jiewu L Hao Z Douxi Y Qiang L Xin C Ding Z 2018 Digital twin-driven manufacturing cyber-physical system for parallel controlling of smart workshop Journal of Ambient Intelligence and Humanized Computing