THE RUSSIAN SOCIETY FOR NON-DESTRUCTIVE TESTING
AND TECHNICAL DIAGNOSTICS

"NDE 4.0: Intelligent measuring transducers for advanced cyber-physical systems of smart factories. Structure, standardization and metrological support "

Vladimir Syasko

«You don't have to change. Survival is not an obligation…»

(W. Edwards Deming)

FROM INDUSTRY 4.0 TO NDE 4.0

STRATEGIC INITIATIVE „INDUSTRIE 4.0" (GERMANY)

The Strategic Initiative Industrie 4.0 (2011) is defined as means of increasing the competitiveness of the manufacturing industry in Germany through the enhanced integration of <u>''cyber-physical systems'', or CPS</u>, into production processes based on a <u>single phisical and information space</u> allowing in the future that the elements of production systems and systems as a whole will <u>interact without human intervention.</u>

4th INDUSTRIAL REVOLUTION – INDUSTRY 4.0 *(Industrie 4.0, Industrie du Futur, Produktion 2030, 4IR, …)*

The Fourth industrial revolution began at the turn of the millennium and builds on the <u>digital revolution</u>. Its main features are:

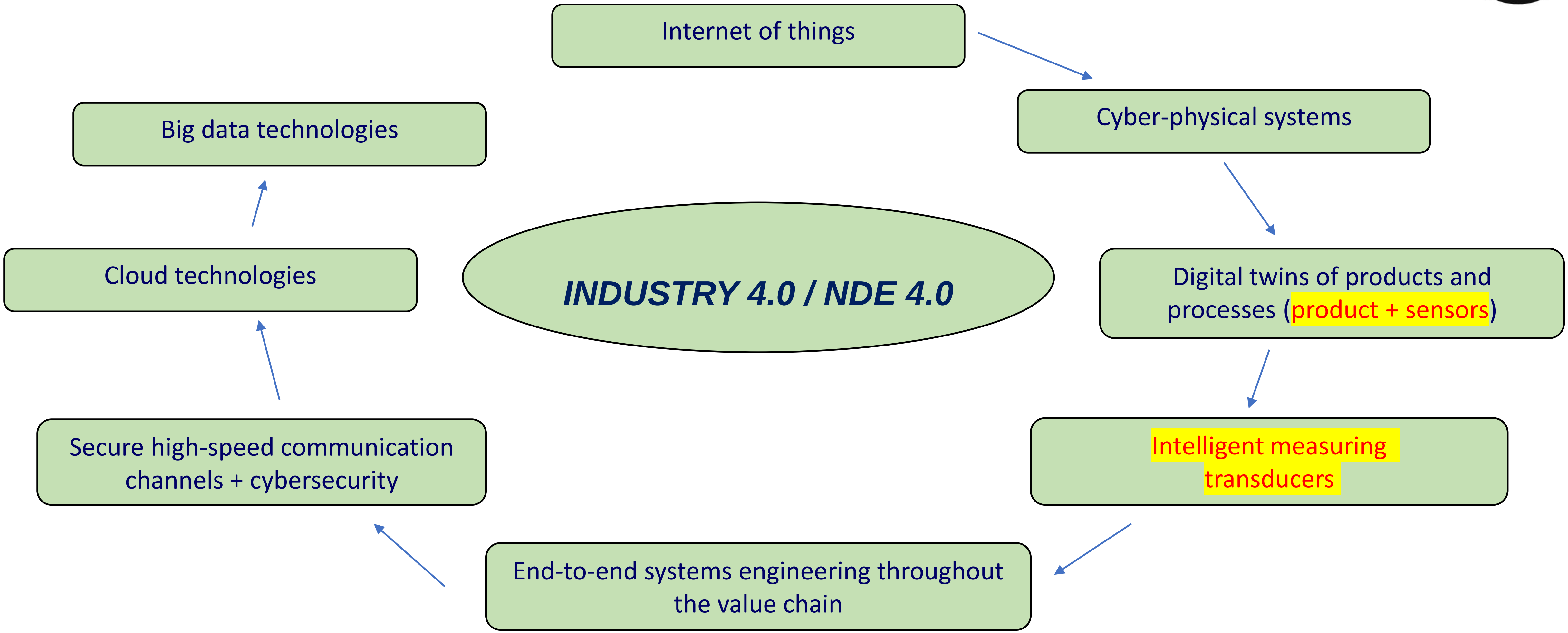
- ***''ubiquitous'' and mobile Internet,***
- ***miniature manufacturing devices (cyber-physical systems - CPS),***
- ***artificial intelligence***
- ***learning machines.***

Klaus Schwab ''The Fourth Industrial Revolution'', the World Economic Forum, 2016.

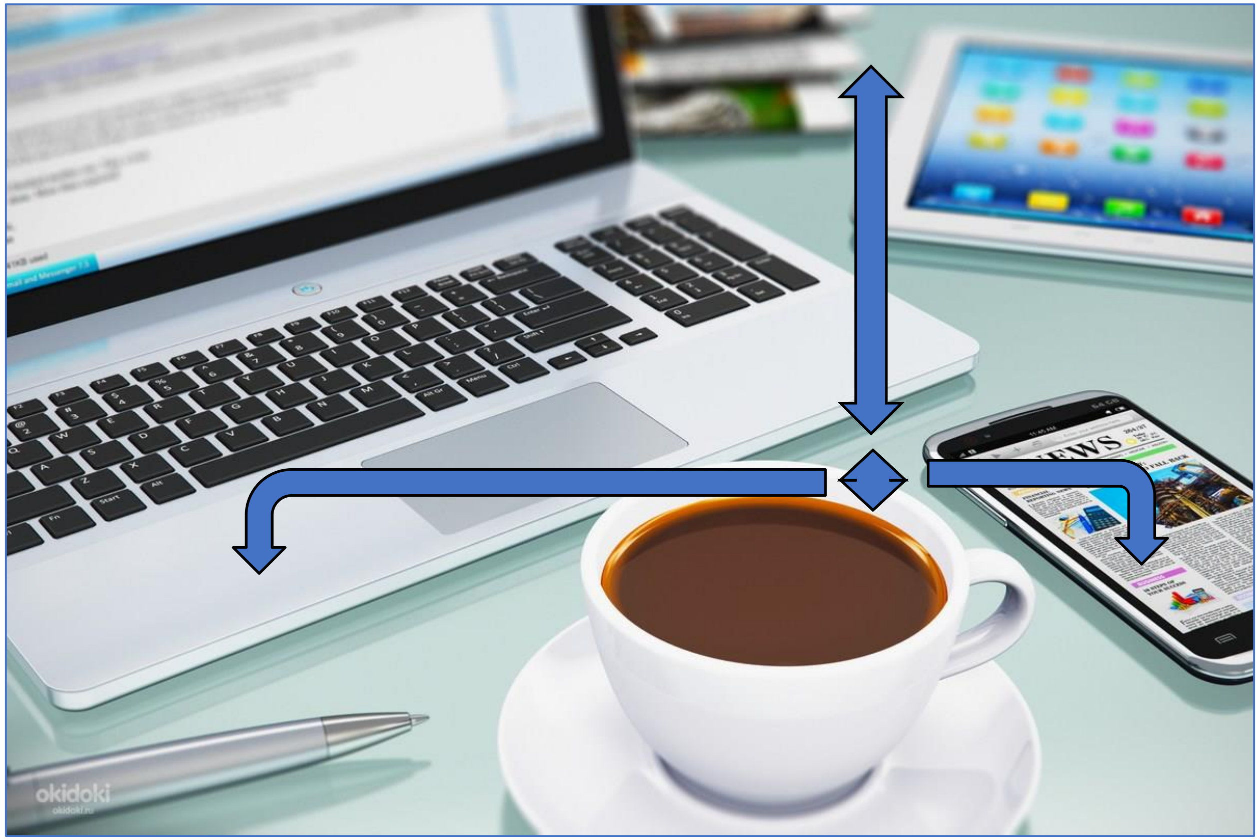
NON-DESTRUCTIVE EVALUATION 4.0

NDE 4.0 is a field of knowledge about physical methods and devices for detecting inhomogeneities of materials and products, as well as determining their geometric and physic-mechanical characteristics, in order to quantify the structural integrity and compliance with the specified design parameters using the basic technical ideas and principles of the organization of smart factories - INDUSTRY 4.0, (including uniform principles of standardization and metrological support). The purpose of the development of this direction is to build networks of connected intelligent sensors that form large systems embedded in the infrastructure of distributed "smart" enterprises/ industries, the development of related engineering disciplines as the basis for ensuring the autonomous long-term functioning of these systems based on realistic models of NDT and CM tools embedded in robotic systems using deep/machine learning, followed by implementation of the principles of artificial intelligence in NDT and CM, taking into account the trends of INDUSTRY 4.0, as well as solving problems, associated with the transition from automated to automatic NDT and CM within the full life cycle of complex technical systems and high-tech products

KEY TERMS / DIRECTIONS OF INDUSTRY 4.0 / NDE 4.0

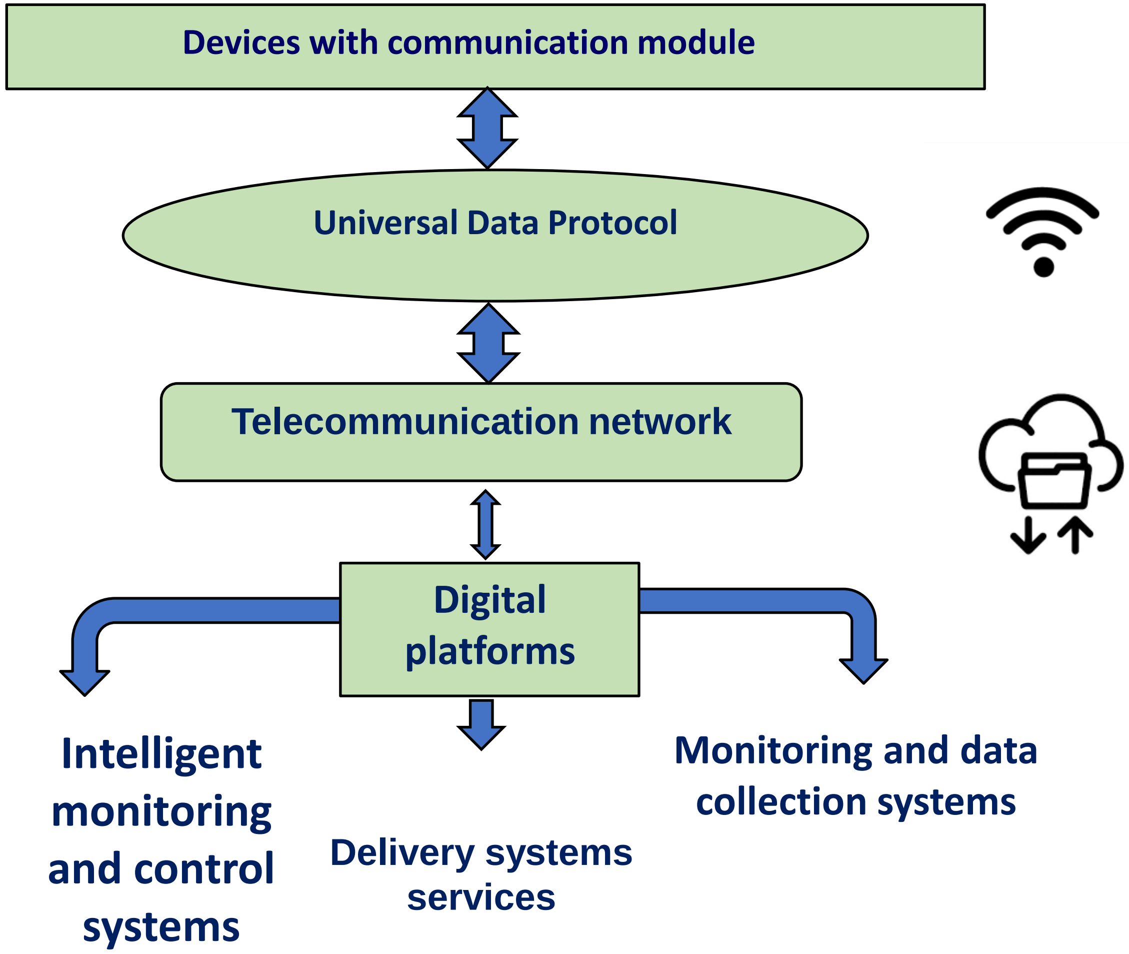


INTERNET OF THINGS



Coffee cup = thing

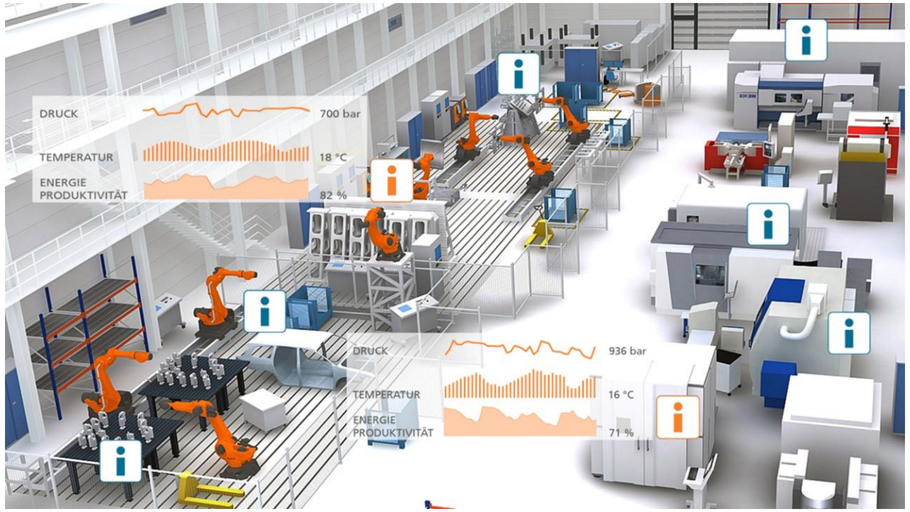
Coffee cup + sensors with communication module = internet thing



KEY DIRECTIONS OF THE 4th INDUSTRIAL REVOLUTION IN TECHNOLOGIES

SMART (MANUFACTURING) SYSTEMS = INTERNET OF THINGS + CYBER-PHYSICAL SYSTEMS.

РОНКТД



Automated devices

Automated devices with communication module

Telecommunication network

Multilevel distributed computer system for data processing, operational management and management decision making

(Cloud technologies, big data, digital models (twins), digital (interpreting) models)

UNIFIED PHYSICAL AND INFORMATION SPACE

KEY DIRECTIONS OF THE 4th INDUSTRIAL REVOLUTION IN TECHNOLOGIES

CYBER-PHYSICAL SYSTEMS (CPS)

Robotic devices

Communication network

Computer control system and data processing using digital intelligent models

Communication network

Cloud technologies, big data, digital (interpreting) models

Body for making managerial decisions and setting objectives

Communication network

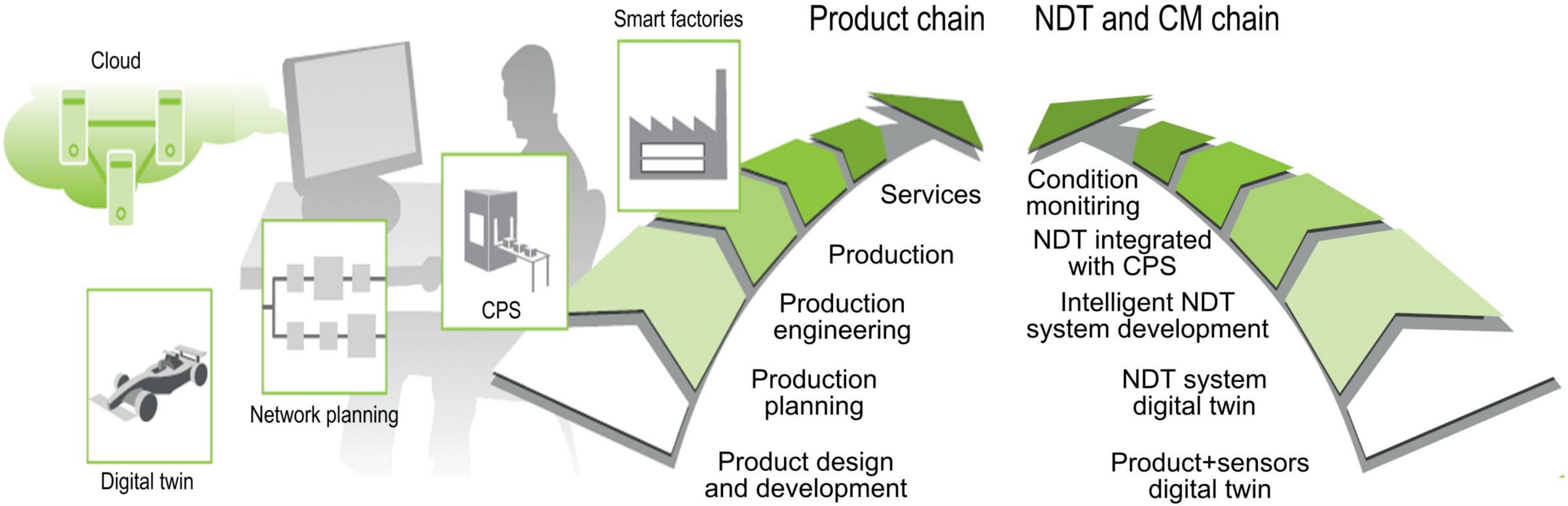
Control commands and input information

- Full automation
- Fully interconnected systems
- Machine for communication with machines (based on uniform principles of hardware and software construction)

UNIFIED PHYSICAL AND INFORMATION SPACE

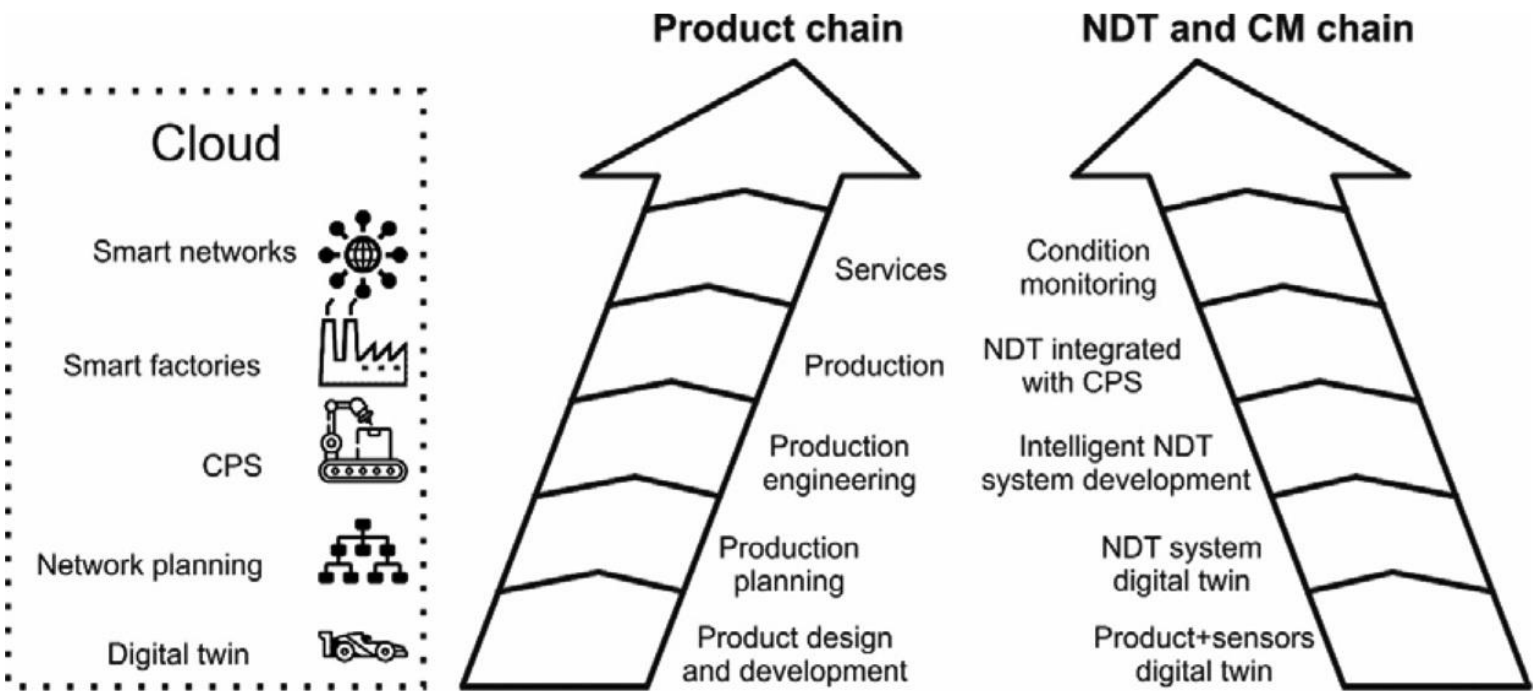
INTEGRATION OF NDT AND CM SYSTEMS INTO A UNIFIED DIGITAL CHAIN OF PRODUCT DEVELOPMENT IMPLEMENTING PRINCIPLE

Digital end-to-end engineering across the entire value chain of both the product and the associated manufacturing system



The development of a product, process and technology for its manufacture, service and NDT and CM systems is a single whole, based on the unified principles of standardization and metrological provision.

INTEGRATION OF NDT AND CM SYSTEMS INTO A UNIFIED DIGITAL CHAIN OF PRODUCT DEVELOPMENT IMPLEMENTING PRINCIPLE



End-to-end system engineering across the entire value chain with integrated NDT and CM

DEVICE MANUFACTURING TASKS IN THE FIELD OF NON-DESTRUCTIVE TESTING IN THE FRAMEWORK OF INDUSTRIE 4.0 INITIATIVE

РОНКТД

Smart mean of measurement (NDT)

intelligent autonomous primary measuring transducer with functions:

- self-monitoring;
- self-recovery;
- automatic calibration;
- wireless connection through the Internet

virtual secondary measuring transducer:
based on multilevel digital model "measuring transducer-inspected object" in cloud

NDT database (measurement results)
integrated in unified database of distributed production and machine data processing (condition monitoring) in cloud

STRUCTURE OF PERSPECTIVE INTELLIGENT MEASURING TRANSDUCERS AND THEIR LINKING WITH CPS OF SMART FACTORIES

intelligent autonomous primary measuring transducer that implements self-monitoring, self-recovery and auto-calibration

robot

communication channel via the Internet

Hardware and software equipment of wireless communication channel

virtual secondary measuring transducer based on digital model "measuring transducer – inspected object" in cloud

Cloud technologies, big data, multilevel digital models, digital twins in cloud

multilevel distributed production system

- full automation
- increased reliability
- extended calibration/verification interval
- non-contact measurements

\+

single physical and information space

INTELLIGENT AUTONOMOUS PRIMARY MEASURING TRANSDUCER (SENSOR), IMPLEMENTING THE FUNCTIONS OF METROLOGICAL SELF-MONITORING, SELF-RECOVERY AND AUTO-CALIBRATION (SUGGESTED TERMS AND DEFINITIONS)

РОНКТД

intelligent sensor: adaptable sensor with function of metrological self-monitoring

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adaptable sensor: a sensor whose parameters and/or working algorithms may change during the operation depending on external signals.

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metrological correct condition of sensor during operation: the state of the sensor in which its measurement error during operation under operating conditions is within the established limits.

metrological self-monitoring of sensor: automatic verification of the metrological correct condition of the sensor during its operation, carried out by using the accepted reference value formed by using a mean built into the sensor (measuring transducer or measure) or a dedicated additional parameter of the output signal

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- ***metrological direct self-monitoring of sensor:*** metrological self-monitoring of a sensor, carried out by evaluating the deviation of the measured value from the accepted reference value, formed by an embedded mean (measuring transducer or measure) of higher accuracy.

- ***metrological diagnostic self-monitoring of sensor:*** metrological self-monitoring of a sensor**,** carried out by assessing the deviation of the parameter characterizing the critical component of the measurement error from the adopted reference value of this parameter:
  - based on structural redundancy
  - based on temporary redundancy

INTELLIGENT AUTONOMOUS PRIMARY MEASURING TRANSDUCER (SENSOR), IMPLEMENTING THE FUNCTIONS OF METROLOGICAL SELF-MONITORING, SELF-RECOVERY AND AUTO-CALIBRATION (SUGGESTED TERMS AND DEFINITIONS)

РОНКТД

Intelligent sensor must have a digital output and ensure transfer of information about the metrological correct condition through an interface.

With its computing potential, the intelligent sensor allows:

- an automatic correction of the measurement error, that occurred as a result of influencing quantities and/or aging of the components;
- self-recovery in the event of a single defect in the sensor;
- self-learning.

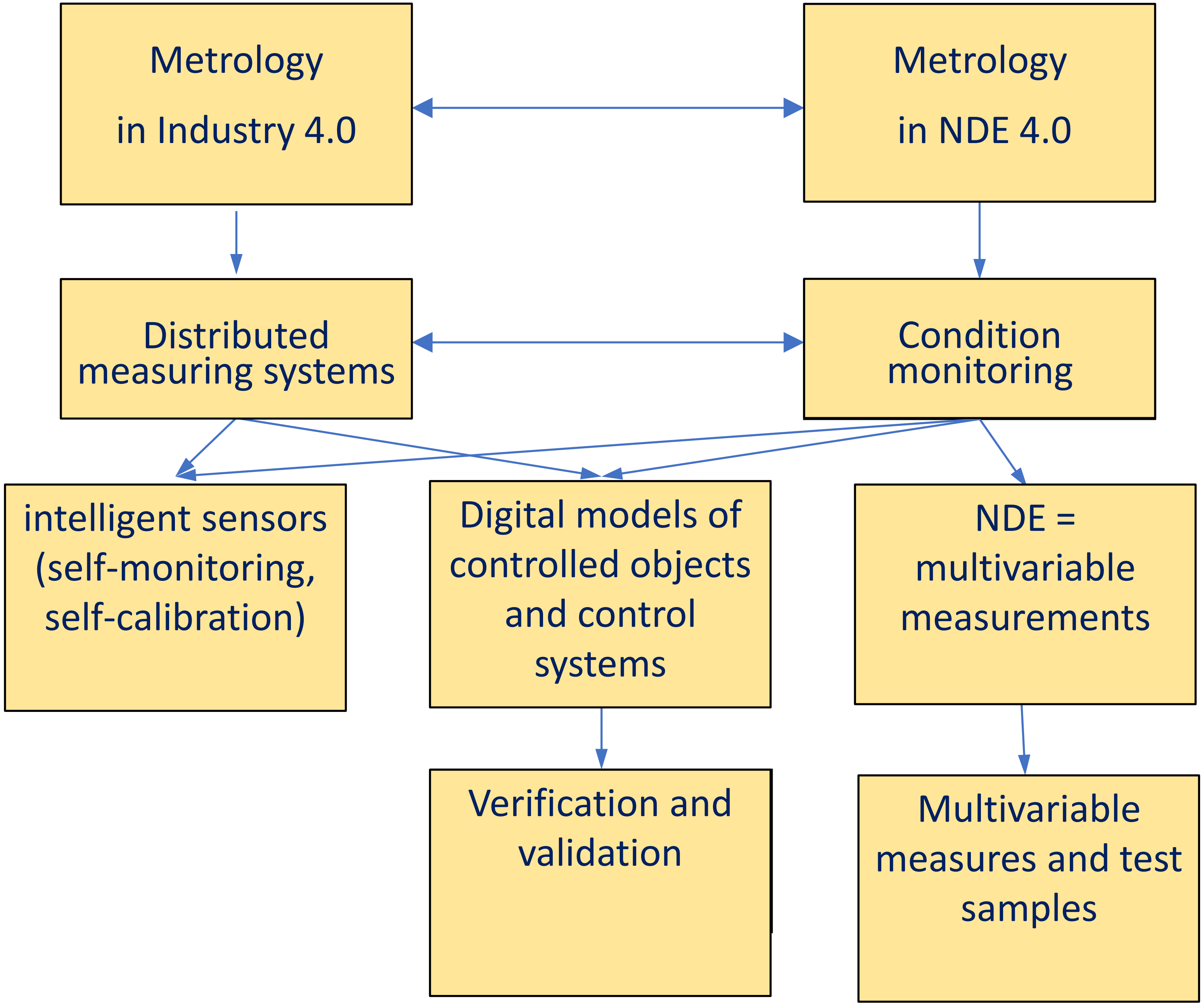
Metrological self-recovery: *an automatic procedure to mitigate the metrological consequences of a defect, i.e. fault resilience procedure.*

Metrological fault resilience: the ability to maintain metrological characteristics within acceptable limits in the event of a single defect.

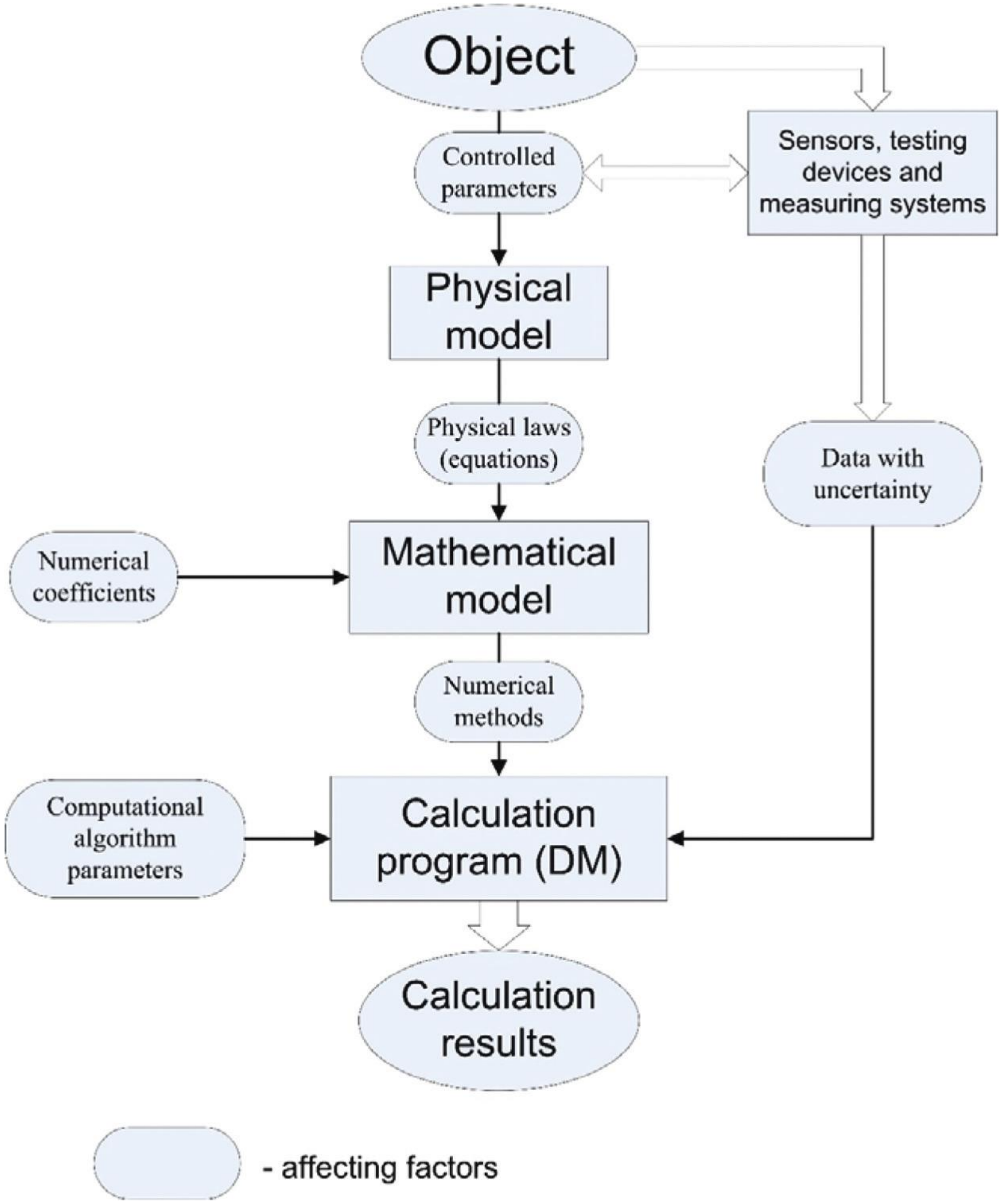
Self-learning: *the ability to automatically optimise parameters and algorithms of work.*

Intelligent sensors will create a technical basis for the implementation of automatic NDT and CM, the establishment of significantly increased values of verification (calibration) intervals with guaranteed reliability of the results, which will ensure their operation as part of smart cyber-physical systems and factories.

KEY TASKS OF METROLOGY IN NDE 4.0



FACTORS AFFECTING THE DEVELOPMENT AND OPERATION OF A DIGITAL MODEL (TWIN)



Tasks for metrological certification of digital models:

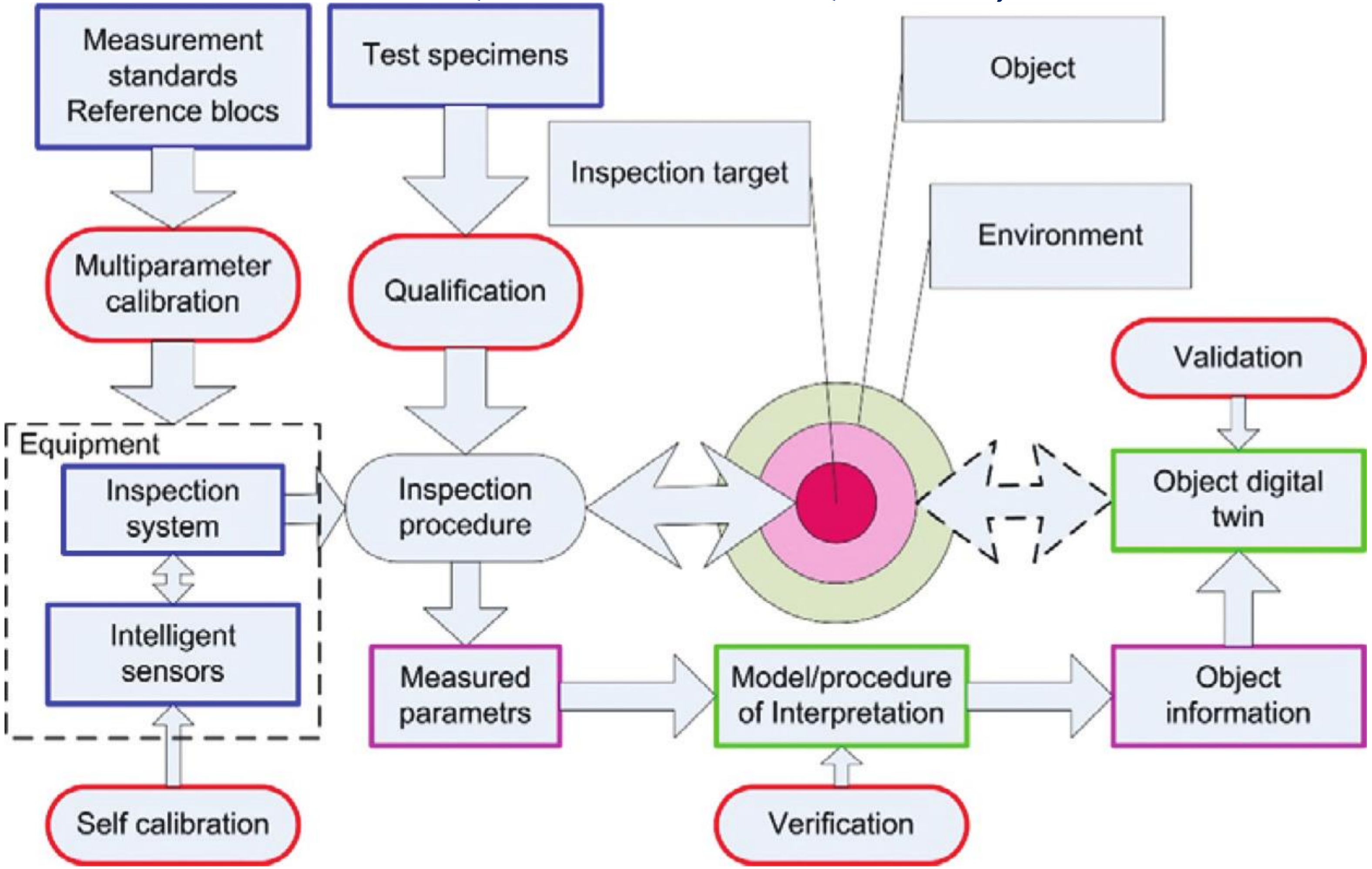
1. **Evaluation** of the influence of the computational algorithm parameters, including the adequacy of the applied physical laws (equations) and applied numerical methods.

2. **Analysis** of the influence of DM numerical coefficients errors on the calculation result.

3. **The study** of the input data uncertainty influence.

4. **The study** of the stability of their work in the event of distorted information or its absence due to malfunction of sensors or data transmission channels.

NDT SYSTEM WITH ELEMENTS OF QUALIFICATION OF EQUIPMENT, METHODS AND DIGITAL MODELS



Qualification for NDT inspection systems:

- Ensuring the traceability of measurement information to the primary standards (unity and reliability of the source data)
- Technical and methodological solutions that ensure self-monitoring and self-calibration of intelligent sensors
- Metrological support and validation of computational models (digital twins) of inspected objects
- Definition and standardization of the metrological characteristics of communication channels that affect the

LEVELS OF STANDARDIZATION AND INDIVIDUAL ISSUES TO BE STANDARDIZED:

1. Sensors:

● Methodological and technical approaches to the development of “smart” and “intelligent” sensors. Currently, there is experience in developing such standards in the Russian Federation.

2. Testing devices:

● The format of the digital passport of the testing device, including, in particular: a unique identification number, type, and name of the device, name of the manufacturer, main technical characteristics.

● The format of the digital certificate of conformity (calibration certificate).

● The standards developed for measuring instruments can be taken as the basis of these standards, while the features for NDT devices should be taken into account.

3. The format and transmission protocol for the primary information:

● The format for the presentation of measurement information, taking into account the specifics of various types of NDT

● Universal data transmission protocol.

4. Software and hardware platforms for data acquisition and processing:

● Universal formats for the acquisition and storage of information.

● Rules for the use of digital models for processing source data.

● Formats for placing data in the “cloud” storage.

● Information security requirements.

In the field of standardization, as the basis of unity of solutions, the practical elements of digitalization are becoming more and more interdisciplinary.

NDE 4.0

DEVELOPMENT OF NDT AS AN INTERDISCIPLINARY SCIENTIFIC AND TECHNICAL DIRECTION AND STANDARDIZATION OF PROCESSES

Building networks of connected intelligent sensors that form large systems built into the infrastructure of distributed "smart" enterprises / industries, the development of related engineering disciplines as the basis for ensuring the autonomous long-term functioning of these systems based on realistic models of NDT and CM tools built into robotic systems using deep / machine learning with the subsequent implementation of the principles of artificial intelligence in NDT, CM and TD, taking into account the trends of INDUSTRY 4.0. Solving problems related to the transition from automated to automatic NDT and CM within the full life cycle of complex technical systems.

PS. Currently, the Russian Society for NDT and TD participates jointly with the metrological community (Rosstandard), as well as GAZPROM, TRANSNEFT, ROSTEC corporations and a number of other concerns in creating a single national metrological cloud, within which an attempt is being made to solve the above tasks within the framework of unity of approaches, which unfortunately has not been possible to do at the interstate level.
In particular, the development of a single European metrological cloud is stuck in the issues of harmonization of approaches.