CYBERNETICS AND PHYSICAL SYSTEMS FOR TRANSPORT MANAGEMENT

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ABSTRACT

The article describes the results of a study of a cybernetics and physical system (CPS) as a transport management tool. The relevance of the topic is due to the need to improve management of complex transport systems in the face of increasing volumes of information and multidimensionality of management situations. The study is based on an assessment of the experience and new opportunities for using CPS in transport management. The article introduces the conceptual and component models of CPS, shows their similarities and differences with other systems. As a methodological tool, the authors used system and structural analysis. The communication features of CPS are revealed, which are a condition for its implementation in organization of high-speed traffic. CPS is evaluated as one more step towards the creation of intelligent systems of a new generation.

Keywords: transport, cybernetics and physical systems, management, embedded systems, ubiquitous computing, Internet of things, technology, management models.

Background. *The problem of transport management is closely related to the modern problem of «Big data» [1, 2]. The increasing complexity of management situations and management systems requires the use of radical scientific solutions. Distributed intelligent network management based on the use of cybernetics and physical systems [3] can be an appropriate option.*

Cybernetics and physical systems or cyber-physical systems (CPS) use intelligent intra-network modeling. Conceptually, the mechanism of their operation is analogous to multi-agent systems [4], but with greater mobility of agents and inclusion of distributed collective computing in this environment. The implementation of intra-network intelligent modeling can significantly improve the efficiency of transport management and its infrastructure, especially in complex and emergency situations. Cyber-physical systems are covered in the literature quite widely. It is written less about their application for management of transport that is caused by necessity of research on special technologies and models. This makes the analysis of real conditions and model schemes for implementation of the emerging approach actual.

Objective. *The objective of the authors is to consider cybernetics and physical systems for transport management.*

Methods. *The authors use general scientific and engineering methods, comparative analysis, evaluation approach.*

Results.

Technologies for CPS support

Cyber-physical systems were created on the basis of integration of a number of previous technologies. The basic technologies for supporting cyber-physical systems include: Internet technology of things (IoT), embedded systems, Ubiquitous computing technology, special technologies for network exchange.

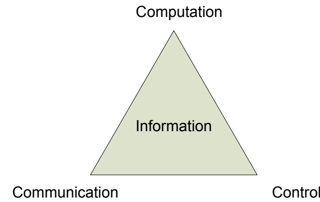
Internet of Things (IoT) – a technology [5], in which any physical object can be connected to any other physical object. Structurally, IoT can be represented as a special network or a distributed system, including interworking of physical devices, vehicles, buildings and other objects built into the electronics (software, sensors, actuators). IoT technology allows objects, united in this special network, to collect data and exchange them. In the aspect of information processing and calculations, the IoT is considered and called a computer network. The difference between IoT as a system from conventional communication systems (usual network, usual Internet) is the presence of the ability to independently perform computing operations. This feature is essentially developed in CPS.

In 2013, the Internet of Things Global Standards Initiative (IoT– GSI) defined IoT as an «information society infrastructure» [6]. The Internet of things technology allows capturing and monitoring objects remotely through the existing network infrastructure. In this way it creates opportunities for integrating the physical world into computer systems, which facilitates the conditions for functioning of CPS. If IoT is supplemented by sensors and drives, then this technological system is transformed into a more general class of distributed systems – cyber-physical systems.

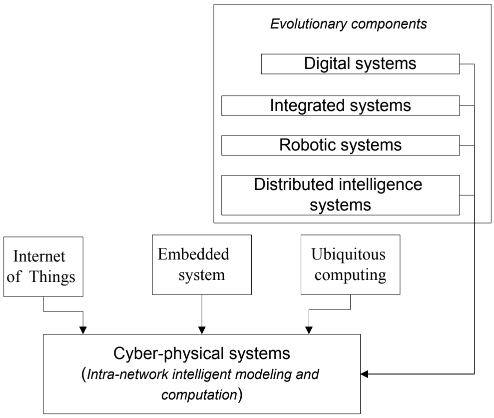
In practice, the Internet of things is treated as a technology, as a network and as a communication system. This is due to the main functions of IoT: service, communication and information. All these functions are related to technology and technological component. Unlike IoT, the cyber-physical system is treated exactly as a system. This is due to the fact that its core elements are technical devices: actuators and a distributed system of sensors and drives. The technological component remains ancillary. CPS is more closely compared to IoT.

Embedded system (ES) is an important technical and technological component of CPS. This component is a computer system with specialized functions as part of a large mechanical or management system. Moreover, it often has real-time limitations on computational capabilities [7]. ES is integrated as part of a complete device, including hardware and mechanical parts. The main purpose of embedded systems is to control other devices. Ninety-eight percent of all microprocessors are manufactured as components of embedded systems [8].

Modern embedded systems are often based on microcontrollers (CPU with built-in memory). The processor used in the ES is of different types, from general purposed to specialized. A common class of dedicated processors is a digital signal processor (DSP). Embedded systems range from handheld devices, such as digital watch and MP3-players, to large stationary installations such as traffic lights, on-board computers that manage fuel consumption in a car, hybrid cars, MRI and avionics. The complexity varies from one microcontroller to high-



Pic. 1. Trinitarian conceptual scheme of CPS.



Pic. 2. Component model of a cyber-physical system.

level systems with multiple devices, peripherals and networks installed inside a large chassis or a body.

For the first time embedded systems were used for driving vehicles, albeit in the space industry. One of such pioneer systems was Apollo Guidance Computer, developed as an element of the Apollo project. An earlier version of the embedded system was the Autonetics D-17, a computer produced in 1961 to control the Minuteman missile. In 1966, the D-17 was replaced with a new version.

In transportation processes, the built-in systems are regularly used. Inertial guidance systems and GPS receivers are based on them. They contain various electric motors – brushless DC, asynchronous motors and DC motors – that use electric/electronic motor controllers. Cars, electric cars and hybrid cars are increasingly using embedded systems to maximize efficiency and reduce pollution. Other automotive built-in security systems make part of anti-lock brake systems (ABS), electronic stability control (ESC/ESP), traction control (TCS) and automatic all-wheel drive. Such an abundance of examples in the analogue sphere creates prerequisites for application of CPS in railway transport.

Ubiquitous computing is a technological component of CPS. Ubiquitous computing is an obligatory component and a distinctive component of CPS. They define the difference between cyber-physical systems from systems of conventional actuators and passive distributed systems. Ubiquitous computing creates the possibility of independent analysis and processing of information within CPS.

As an independent concept, ubiquitous computing exists not only in CPS, but also in software engineering [9] and computer science, where calculations are made at any time and everywhere. Unlike the use of desktop computers, ubiquitous computing can occur using any device, anywhere and in any format. A user interacts with a computer that can exist in many different forms, including portable ones, tablets and terminals, in such household objects as a refrigerator or glasses. Core technologies to support ubiquitous computing include the Internet, advanced middleware, operating system, mobile code, sensors, microprocessors, I/O interfaces and user interfaces, networks, mobile protocols, location and positioning.

This technology is also treated as pervasive computing [10], ambient intelligence [11], or everyware [12]. Each term emphasizes certain aspects of technology. In addition, this technology is called: physical computing, the Internet of things, tactile computing. Instead of offering a single definition for these related terms, a taxonomy of properties was proposed for ubiquitous computing, from which various kinds or varieties of ubiquitous systems and applications can be described.

Ubiquitous computing covers a wide range of research topics, including distributed computing, mobile computing, local computing, mobile networks, context-sensitive computing, sensor networks, human-computer interaction and artificial intelligence. In fact, it turns out that this technology complements other technologies for formation of cyber-physical systems and ensures their adaptability and activity.

Cyber-physical system development

Cyber-physical systems arose as a result of development of technical facilities and computing technologies. Pic. 1 shows a trinitarian [13] conceptual scheme of a cyber-physical system. It is defined by three entities: communication, calculation and control, which are united via information. The main functions of cyber-physical systems are information processing (computation), intellectual communication and control.

Pic. 2 shows a component model of a cyber-physical system, which includes two groups of components – evolutionary and technological.

Evolutionary components served as a basis for emergence of prerequisites for creation of CPS. Technological components serve as a basis for implementation of a specific CPS. They are discussed above. Naturally, implementation of the system can be different, because it adapts to the «task».

Of great importance are the cyber-physical systems for large-scale distributed automation and control systems, including the sphere of transport.

General characteristics and models

Cyber-physical systems are highly adaptive, so their implementation depends on the task being put and the control object. The expediency of using cyber-physical systems arises when managing complex systems and complex management situations. In terms of computing, CPS can be compared to parallel computing systems. For simple situations, they are inefficient, and for complex ones they are irreplaceable.

The disadvantage of CPS is their complexity, which requires involvement of specialists to create and support them. The complexity of cyber-physical constructions causes complexity of the general definition of these systems. In practice, the definition is given through enumeration of functions. Therefore, it is possible to give several definitions of CPS in different aspects.

In the aspect of integrated systems, cyber-physical systems are a complex of computational, network and physical processes.

In the aspect of management, cyber-physical systems are distributed control systems that contain embedded computers and compute nodes and control physical processes.

In the aspect of the calculation methodology, cyber-physical systems are distributed control systems that contain feedback loops in which physical processes affect computations and vice versa.

The models used in CPS are divided into conceptual, mathematical, managerial, technological and basic. CPS as a control system is focused primarily on management of mobile objects [14]. At the same time, it should be noted that one of the goals in creation of CPS was reflection of cyberthreats and other threats.

This goal has been preserved for the time being. However, such a possibility means that CPSs are adapted to work with rapidly changing situations and changing goals. This creates an advantage for them as multi-purpose control systems [15].

Conceptual models of CPS are based on information structures [16]. Basic models are built on the basis of information units. Information units form a language environment, which, in accordance with the theory of semiotic control, serves as a basis for intellectual management. In the aspect of interaction, cyber-physical systems use a new type of models of information-physical interaction. In the aspect of network interaction, cyber-physical systems use a new type of models of network interaction – intra-network online modeling. In the aspect of intellectual information processing, cyber-physical systems use a new type of self-verified models and models of internal online optimization.

It is the presence of intelligent models that makes CPS resistant to cyberattacks and improves their security. This property is important in ensuring traffic safety in transport.

The focus on application of CPS for transport sector in the form of transport cyber-physical systems (TCPS) is singled out. In this case, two qualitative types of TCPS are identified: an internal system inside a moving object and an external system that unites a complex of moving objects, for example, within a metropolis. Systems of the second type solve the problem of controlling traffic in a system of transport flows [17]. Systems of the first type solve the task of controlling an individual object in a complex dynamically changing situation [18], for example, a high-speed train or a ballistic missile in an anti-missile situation.

Conclusions. *While there is no formal and strict definition of the concept of a cyber-physical system, although in a number of works the characteristic properties of such systems are formulated. The fundamental property of CPS is inclusion of intelligent information processing nodes in their structure. This relates them to distributed intelligence systems.*

CPS are more complex control systems in comparison with all existing transport management systems, including ITS. CPS are considered as distributed network systems, but differ from communication systems by the presence of intelligent nodes and the property of self-verification and online modification of flows. In ordinary network systems, this is done externally by a user.

The experience of applying CPS in the transport sector (primarily aviation and missile technology) gives a reason to see them and CPS in the field of railway transport, primarily high-speed railways [14]. CPS, in contrast to ITS, is more resistant to cyber attacks, due to availability of autonomous control and the principles of self-regulation.

In general, the analysis of the possibilities of CPS allows us to hope for progress in mastering cyber-physical approaches and management models, integrating executive and sensory devices into a single complex, transforming individual intelligent nodes into a classical automated control system. The continuation of all research in the field of CPS should be considered productive, the same can be said about future CPS studies regarding the theory, technologies, and electronic support of information processes.

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