Multi-agent model of information interaction among unmanned vehicles

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Abstract. This research covers the issues of modeling information interaction among elements in a complex cyberphysical system using the multi-agent approach. A multi-agent model of the information interaction of unmanned vehicles is provided, as well as a set-theoretic description of agents in the cyberphysical system and their interactions is described.

1. Introduction
Currently, due to the development of the Industry 4.0 paradigm [1], the cyberspace of transport systems is actively developing in the world. These are complex cyberphysical systems that appear as a result of interaction among people, software, and Internet services through technological devices and communication networks [2].

When considering cyberphysical systems, it is necessary to evaluate the security of such system from the information interaction point of view. The key factor is a hackers gaining the ability to influence physical and production processes through informational interaction.

Due to the peculiarities of the structure of such systems, attacks on them can be carried out both intentionally (by cyber criminals) and by negligence (by employees who have access to the cyberphysical systems). Consequently, the harm done to the system can be either direct (loss of information, disabling the system), or indirect (spamming). In addition, there may be a violation of information security without human intervention, if the system implementation involves its independent development.

In further research of cyberphysical systems, unmanned vehicles will be considered as objects of smart transportation systems (Smart Transportation) [3].

2. An unmanned vehicle as a vulnerable object of a cyberphysical system
An unmanned ground vehicle (UGV) is a vehicle that works when in contact with the ground and without the onboard presence of a person [4].

An unmanned vehicle combines five technology groups: 1) a human-vehicle interface; 2) sensors that provide data on the operation of the vehicle and its parts; 3) sensors that provide data on the external road environment, sources of dynamic data in real time about the area around the vehicle; 4) automatic control of the operation and functions of the vehicle; and 5) artificial intelligence, which combines the operational data in the car with external data on the roads and uses it to activate automated vehicle controls [5].
Unmanned vehicles interact through the network with the environment using the following interfaces [6,7]: vehicle-to-vehicle, V2V; vehicle-to-infrastructure, V2X; vehicle-to-pedestrian, V2P; vehicle-to-grid, V2G; vehicle-to-device, V2D), as well as in intelligent transport systems (Big Data + BI (Business Intelligence), figure 1.

![Diagram of unmanned vehicles interaction](image)

**Figure 1.** The scheme of interaction of unmanned vehicles in the infrastructure of the cyberphysical system of a smart city.

Vehicle-to-vehicle (V2V) is a wireless communication system that allows two vehicles to exchange information with each other on the roads without human intervention. A car can use information about other vehicles nearby to calculate its current and future position. Implementation of this interface provides a number of technological safety services to prevent accidents or predict dangerous situations.

Vehicle-to-infrastructure (V2I) is a wireless communication system that allows cars to exchange information with infrastructure objects, for example, with traffic lights, and traffic signs. Depending on the load of road traffic, devices exchanging information via the V2X interface can offer road users alternative routes or parking places near public transport stations for the combined use of multiple modes of transport.

The vehicle-to-pedestrian (V2P) interface is designed to organize the interaction of the vehicle with pedestrians in the immediate vicinity. As part of this interaction, the car’s electronics will be able to identify the frequency range of smartphones used by pedestrians, which will allow the vehicle to evaluate the speed and direction of movement of the mobile gadget, and accordingly the pedestrian. This will signal the hazard to both the driver and the pedestrian.

In relation to the unmanned vehicles as a cyber-physical object in the Smart Transportation infrastructure, three zones of vulnerability can be identified:

- Motion control systems: data storages (navigation maps, routes) and dynamic data and command streams transmitted over various networks, processed in automated systems and presented on a display in graphical or text form;
- Technical infrastructure: technologies, system software, devices with which the implementation of the basic commands for the management of unmanned vehicles is carried out.


Information interaction of the subjects of the “smart city” using information received from the unmanned vehicles (transmitted by the unmanned vehicles) and processed through the technical infrastructure.

The close integration of cyberphysical systems with technological processes associated with the management of a large number of unmanned vehicles capable of changing their behavior leads to the need to create new models for describing information interaction and ensuring the information security of such systems. One approach to formulating a conceptual model of the Smart Transportation infrastructure is multi-agent modeling [8, 9]. Multiagent systems technology is a new paradigm of information technology focused on the sharing of scientific and technical achievements and advantages that provide ideas and methods of artificial intelligence, modern local and global computer networks, distributed databases and distributed computing, hardware and software tools to support the theory of open systems [10]

3. Multi-agent system model

The mathematical model of a multi-agent system of information interaction of unmanned vehicles in the conditions of infrastructure Smart Transportation can be represented as follows:

$$MAS = \langle Agent, Type, Com, Env, Stat, Res \rangle,$$

where $Agent = \{A_1, A_2, \ldots, A_{Type}\}$ – set of all system agents; $Type$ – agent type from the set of possible types (roles) of agents in a multi-agent system $Type \in T$; $Com = \{C_1, C_2, \ldots, C_n\}$ – the set of all possible connections between system agents; $Env = \{E_1, E_2, \ldots, E_0\}$ – set of all possible system environments; $Stat = \{S_1, S_2, \ldots, S_s\}$ – the set of all possible states of the system; $Res = \{R_1, R_2, \ldots, R_r\}$ – the set of all possible system resources.

A generalized model of an intelligent agent can be represented as follows:

$$Agent = \langle Name, Type, M_{IMS}Type \rangle$$

where $Name$ – intelligent agent name; $Type$ – agent type from the set of possible types (roles) of agents in a multi-agent system; $M_{IMS}Type$ – model of the information and control space of the agent of the cyberphysical system of a smart city. Whereas:

$$M_{IMS}Type = \langle KB, f, Inp, Out, RA, Script \rangle$$

where $KB$ – agent knowledge base; $f$ – local agent target $f \in F$; $Inp$ – agent input data stream; $Out$ – agent generated information flow; $RA$ – agent resources $RA \in R$; $Script$ – agent behavior script from many possible scenarios $Script \in SC$.

As part of further research, we will assume that the set $Type$ limited to three types of agent groups:

- $G_1$ – messaging agents Such agents include all participants in the information management space, transmitting information to an unmanned vehicle (pedestrians, infrastructure, other unmanned vehicles);
- $G_2$ – external management agents. Such agents include external unmanned vehicles dispatch services, cloud service support environments within the cyber-physical system of a smart city.
- $G_3$ – agents of internal control of an unmanned vehicle.

The model of the messaging agent $G_1$ is based on structure (3) and is defined as follows:

$$Agent^{G_1} = \langle Com^{G_1}, Inp^{G_1}, Out^{G_1}, Str^{G_1}, RA^{G_1}, Script^{G_1} \rangle,$$

where $Com^{G_1}$ – many intelligent agents that transmit information to the input of this agent and receive messages from it; $Inp^{G_1}$ – agent input data stream; $Out^{G_1}$ – agent generated information flow; $Str^{G_1}$ – message structure; $RA^{G_1}$ – agent resources $RA^{G_1} \in RA$; $Script^{G_1}$ – messaging script.

The model of the messaging agent $G_2$ is based on structure (3) and is defined as follows:
\[ Agent^{G_2} = \langle \text{Com}^{G_2}, \text{Inp}^{G_1}, \text{Out}^{G_2}, \text{Str}^{G_2}, RA^{G_2}, (MSA) \rangle, \]

where \( \text{Com}^{G_2} \) – many agents receiving control messages from this agent; \( \text{Out}^{G_2} \) – agent control flow; \( \text{Str}^{G_2} \) – control message structure; \( RA^{G_2} \) – agent resources \( RA^{G_2} \in RA \); \( (MSA) \) – a situational analysis model in which, based on input signals (changing the situation in the past) and established goals, it is determined whether a change in the current situation in the foreseeable future will lead to a critical state of the cyberphysical system.

\[ MSA = \langle SMA(t-1), SMA(t), SMA(t+1), f^{G_2}, KB^{G_2} \rangle, \]

where \( SMA \) – multi-agent states: \( (t-1) \) – prior; \( (t) \) – current; \( (t+1) \) – projected in the future. \( f^{G_2} \) – set of goals generated by decision maker; \( \text{Str}^{G_2} \) – control message structure; \( KB^{G_2} \) – knowledge base of information situations that potentially leading elements of the cyberphysical system \( KB^{G_2} \in KB \) to the critical state.

Representation level of agents \( G_2 \) includes the following roles of agents for internal management of unmanned vehicles elements and interaction of unmanned vehicles with Smart Transportation infrastructure: \( A_{gs} \) – agent for generating data traffic; \( A_{cs} \) – data traffic classification agent; \( A_{qs} \) – message queuing agent; \( A_{di} \) is a message processing agent.

This article presents a simplified model of agent information interaction within the framework of the Smart Transportation cyber-physical system. The main goal is to explore the possibilities of the proposed approach to multi-agent modeling. A more developed approach to adaptation will be presented in subsequent works of the authors.

4. Conclusion

In this paper, the main interfaces of the interaction of unmanned vehicles with infrastructure objects Smart Transportation are considered. At the system-wide level, the roles of the main agents are defined and the processes of their interaction with the Smart Transportation infrastructure are described. The described approach is the development of the ideology of situational management with the allocation of three roles of agents of a multi-agent system, which will further simplify the modeling of cyber-physical systems with the support of the required level of quality of service.

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