Elements of Cyber-Socially Physical Systems in “Smart Cities”

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Abstract: - The implementation of plans to create "smart cities" as one of the most important areas of the digital economy requires the priority development of transport infrastructure, ensuring the movement of people and goods within the city and adjacent territories. Safe operation and maximum throughput of the resulting cyber-physical system are possible provided that a diagnostic technology is created for transport infrastructure facilities, including video-based road conditions. The author's vision of the problems of mathematical modeling of cyber-physical systems in transport is presented as a three-level hierarchical structure, including environmental sensors at the lower level, data processing centers (DPC) at the middle level and a single data storage center for developing management decisions at the upper level. Prospects for data center modeling based on a multi-agent approach and a technical vision algorithm that is proposed to be implemented as a program on a mobile device to identify objects of transport infrastructure and their defects using stereometry are explored. The presented algorithm can be used in the planning of road repairs and buildings construction, in the analysis of road and buildings accidents by expert engineers, in the processing of applications of inhabitants’ complaints, etc.

Key-Words: - Roads as a Cyber-physical systems, Multi-agent method, Photogrammetry

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1 Introduction
Automation of the diagnostics of state transport infrastructure facilities and the related need to develop modules for mathematical modeling, design and production of devices and diagnostic tools as part of the control system of the transport cyber-physical system, which provides physical accessibility of infrastructure and cities, causing an urgent problem within the concept of "smart cities" as one of the most important directions of digital economy [1]. At first, the quality of the road surface along with the category of the road, its visibility, the width of the roadway, and the location of the suitable road signs has a significant influence on road safety and traffic flow capacity. Together, they define the concept of “road conditions,” on which the trajectory and the car’s speed depend. According to experts the influence of road conditions on the occurrence of road traffic accidents, is from 60% to 80% of cases [2, 3]. Moreover, accidents are one of the most common causes of death in the world. More than 1.35 million people die annually, which is equivalent to the loss by countries affected by this disaster of about 3% of their gross domestic product (GDP) [4]. Secondly, according to the results of road accidents’ analysis, there is need to identify those who are responsible for the violation of traffic rules (traffic regulations) and the cost estimate of damaged auto motor-vehicle’s repair (AMV) [5]. Thirdly, economic and social losses due to a decrease in the traffic flow’s speed and the accounting road’s capacity, caused by the existence of cracks and potholes in the road surface tend to increase with untimely detection and repair [6].

Quite often controversial situations arise, the investigation and examination of which is carried out on available materials, including photographs and video filming. According to the European Protocol, participants in a road incident can use mobile devices to record and register all circumstances (Fig.1).

Fig.1. A driver of the motorcycle recorded a general traffic situation

In fig.2, to understand the scale and size of potholes, the driver used a glove as a marker for...
scale [7]. In this situation, the motorcycle owner will have to prove that the road surface does require operating conditions acceptable for road safety.

![Fig.2. A picture of pothole in the road surface](image)

A definite breakthrough in solving the problem of objective diagnostics of road conditions was mobile systems based on laser scanning [8] (Fig.3). However, the high cost of this technology and the lack of information about the texture of road objects complicate the situation.

![Fig.3. A resulting cloud of laser scanning points includes reflections from people, equipment, vegetation, etc. located on the object](image)

The use of modern inexpensive photogrammetric methods [9-15] for determining damage and unevenness of the road surface and structural elements of the road gives a new impulse to the development of digital technologies for designing road repairs, increasing mobility and reducing the cost of work.

Based on the foregoing, the development of autonomous mobile devices capable of "on the spot" to perform the tasks of collecting and analyzing road data, including photographs and video, in a form suitable for investigation and examination of disputed situations, is an urgent task.

### 2 Cyber-physical Management System of Urban Transport Movement

The considered above autonomous mobile road data collection and analysis devices, which operate as part of a single measuring and processing complex, are an affordable example of cyber-physical systems in transport (Fig.4). This also adds a system of stationary city security cameras for road safety and, possibly, a system of unmanned vehicles, which, having a complex software system of artificial intelligence on board, are able to analyze independently the surrounding situation, make decisions and learn from previous experience.

![Fig.4. Regional and local authorities](image)

As a result, the totality of such devices forms a heterogeneous distributed system of artificial intelligence, which should be enriched by some hierarchical structure, which would provide the distribution of tasks between devices, their interaction with the environment and the exchange of information in accordance with fundamental goals and settings (Fig.5).

![Fig.5. Block diagram of a cyber-physical urban traffic control system](image)

This implies the existence of protocols [16] for their joint work at the lower level of interaction, as well as protocols for sharing in data processing centers (DPC) at the mid-level and further for transfer to a single data center and development of management decisions at the upper level in order to form a global cyber-socio-physical urban traffic management system as part of the concept of creating “smart cities”. The appearance of the word “socio” as applied to the road here is by no means
accidental, since the road is not a factory or field with the prospect of a deserted product, but an indispensable element of the “smart city”, providing accident-free operation and maximum throughput of the transport system, with the presence in it of active road users, creating the effect of unpredictability of conscious or unconscious behavior of people, drivers, pedestrians and etc.

2.1 Prospects for Modeling Data Centers Using Programmable Reconfigurable Logic Arrays

In fig. 6 shows the general organization of a data processing center (DPC) of a cyber-physical system of urban traffic control at the middle level. Here, PE is a processor element based on a sensor or environmental sensor, a PC is a monitor subsystem based on a personal computer, UE is a sensor / sensor interaction control device, TCh is a trunk channel (main bus), RC is a regular channel (modeling system), DF is a decisive field. The modeling system is dashed, in which the authors of [17, 18] use the decisive field on continuous VLSI processor matrices.

The switching environment of each individual sensor or environmental sensor is shown in fig. 7. Here, the BSG is the matrix adjustment signal generation block; SCU – switching control unit; TCh – trunk channel.

The undoubted advantage of the homogeneous architecture of the processor matrices is its high performance in solving image processing tasks and a huge resource of backup and reprogramming for modeling heterogeneous distributed artificial intelligence systems with further equipping with the necessary sensors accompanied by programs for primary processing of the received data and transferring control to the following hierarchical processing levels, data storage and management decisions.

2.1.1 Multi-agent Systems as a Tool for Modeling the Interaction of Environmental Sensors in Transport

Foundations of multi-agent approach were presented in a series of works [19-22], where also the possibility of applying stochastic models for the design and research of multi-agent systems of economic actors were discussed. For systems with swarm intelligence as a model Markov random field was proposed. The agents are located at the top of the final graph and are modeled by random variables. In [23-26] was shown the possibility of using multi-agent technology for solving problems of planning in industry and in [27-29] proposed situational approach to the management of resources and developed a multi-agent platform for development of intelligent systems that preserves the scene in the context of the situation, to improve the quality and efficiency of planning in the process of events’ changes, including the development of methods of receiving and processing actual data from production resources in real time [30]. The study of connected subsets (clusters) of agents deserves special attention. The formation of clusters corresponds to the allocation of road objects, the creation of a production or transport associations. Under the assumption that agents are located at the vertices of a regular lattice, an estimate of the probability of cluster’s existence, penetrating the entire system, can serve the analytical results, obtained for these lattices in the percolation theory [18]. The critical probabilities of nodes and links
serve as lower estimation for the agent’s coefficients availability, which defines the probability of existence of global cluster and coherent subsets of agents [31].

3 Stereo Measurement Solution
The bibliography [10-14] analyzes the key component of the proposed cyber-physical system for diagnosing transport infrastructure objects, the role of which is the technical vision system [9], based on the method of photogrammetric processing of stereoscopic images of a three-dimensional 3D object obtained from different angles.

3.1 Localization and Identification of Projections of Interpolation Points on Images Determined from Reference Frames of a Video Sequence and Forming a Stereo Pair
Highlighting the boundaries of flat images is one of the important auxiliary tasks in recognizing defects in transport infrastructure objects, in particular, damage to the road surface. They contain comprehensive information about their form for subsequent analysis [32-35]. As a preliminary conclusion, we note that the images of objects of transport infrastructure are characterized by the presence of angles formed by the intersections of generators (curves or straight lines). Therefore, for the analysis of such images, it is advisable to use the so-called «angular» filters, in particular, the use of the Harris detector is popular [33, 35].

3.1.1 Experiment Results
To illustrate the photogrammetric method, let’s consider a real stereo pair corresponding to two photographs of a typical road cone against a background of damage in the road surface (Fig.8).

Fig.8. Stereo pair: road cone on the background of damaged road surface

We measured the coordinates of the seven vertices of a three-dimensional object using a ruler. In addition, we fixed the coordinates of the corresponding points on the images in the image editor with the mouse. Given the coordinates of the road surface point on the left and right images, one can evaluate the accuracy of the vision algorithm. In our case, the distance from the top of the cone to the asphalt pavement, calculated according to the Pythagorean Theorem, was 31.975 cm, which is 0.078% different from the value of 32 cm in the technical data sheet.

3.2 Computer Application
To test the ability to automatically search for graphic markers and anchor points in photographs, we suppose to carry out the implementation of the obtained algorithms on a smartphone running the Android OS. Remember that precisely these points must be found on each image in order to successfully solve the problem of photogrammetry. Due to the peculiarities of the image of the defects of the roadway (lack of clear boundaries, the presence of outsiders objects, the insignificance of some defects), it should be possible to “manually” mark the characteristic points on the images. The algorithm for creating such an interface that allows selecting the characteristic points by the movement of the graphical cursor is the following. In succession, the left and then the right snapshot of the stereo pair are reset to the smartphone screen (Fig.9).

Fig.9. Imitation of work with the image on the smartphone screen

An image of a wire model of a 3D object superimposes the whole image. On the model, the
characteristic points of the object flash, and the user by the movement of the graphic cursor selects the corresponding point in the photo. After processing both images of the stereo pair, the algorithm forms linear perspective transformation matrices in the smartphone’s memory (a so-called calibration). Then by a command sent the user selects an arbitrary point in each snapshot of the stereo pair. It is proposed to choose from the appropriate menu the test mode (if it is a characteristic point belonging to the object), or the test mode for the probing of the Pythagorean Theorem (if it is a point on the road base), or to continue to work. Next, by a command sent the user selects the second point in each snapshot of the stereo pair; and the algorithm calculates the distance between selected points (another test). Next, the user selects the third and so on points in each picture of the stereo pair when prompted. As the array of characteristic points filled, it becomes possible using the triangulation technology to construct a three-dim ensional mathematical model of a road surface defect. Then, based on the obtained model, the area and volume of the geometric figure that characterizes this particular damage to the road surface are calculated. A further task is to prepare an order for the repair work to eliminate this road defect. The full cycle of works on the recognition of road surface damage is shown in fig.10.

4 Conclusion
The practical application of the algorithm stated in the report is quite wide, including when fixing and determining the actual dimensions of damage to buildings' construction based on the measured values of body surface points on the left and right images (Fig.11).

Fig.11. Stereo pair: two photos of a concrete bulk damaged in a building accident

Examination of the nature and the list of damages to the buildings' construction (Fig.12) provides for a detailed fixation of the damages to determine the possibility of their formation and involvement in the event under investigation. The corresponding act records the results of the visual inspection of the damaged buildings' construction and photographing. Photographs and inspection report for buildings' construction are a mandatory annex to the expert opinion or report on the assessment of the cost of repairing the buildings' construction.

Fig.12. Ruins of the collapsed concrete floor, submitted for examination

Of course, the photogrammetric method is a weighty argument in solving controversial situations, and the determination of the actual size of damage to the elements of the buildings' construction from photographs and video footage is an urgent task. In conclusion, we should say that the remote collection of data on buildings' construction defects could be
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