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PROBLEMS OF DESIGNING A CONTROL SYSTEM FOR DECISION MAKING SYSTEMS OF CYBERPHYSICAL SYSTEMS

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Abstract: **This work deals with the development of a structural model of decision-making tools for cyberphysical systems and with the development of a control system of decision-making tools for cyberphysics systems. The main difficulties in developing decision-making tools have been considered and analyzed. A structural model of decision making tools for cyberphysical systems and its characteristics has been considered. The estimation of hardware costs for the implementation of decision-making tools of cyberphysical systems has been made. The essence, purpose and properties of the control system have been disclosed. The cybernetic model of control system for decision making of cyberphysical systems has been presented. The basic parameters of the developed model have been given. Also, an experimental mobile cyber-physics system for recognizing objects (road signs) from a video stream for car drivers has been presented.**

Index Terms: **cyber physical systems, means of decision-making in cyber physical systems, decision support tools, control units interlevel connection, power internally tiered control enforcement agents, database, database models, control system of decision-making tools for cyberphysics systems, cybernetic model of control system of decision-making tools for cyberphysical systems, recognition of objects (road signs) from a video stream for car drivers, a video stream.**

I. INTRODUCTION

- Recently, cyberphysical systems (CPS) have been given a lot of attention. Under the cyberphysical system there is the combination of physical processes and cybernetic components [1–3], which provide:
- organization of measurement and computing processes,
- protected storage and exchange of measurement and official information,
- organization and implementation of influences on physical processes.
- combination of such different components requires the creation of new scientific developments that will ensure the efficient operation of the CPS in general. Such a system should provide:
- collection of information from the physical environment,
- processing information according to the specifics of usage,
- storage of information,
- construction of models of the corresponding reaction of the CPS to the information received,
- to predict the changes of the physical environment on the basis of received information,
- assist the user in making decisions,
- make decisions and implement them through the relevant components of the CPS and influence the processes of the physical environment.

Since the main purpose of CPS is the collection, processing of information and the formation of an appropriate reaction of CPS to the physical environment, the decision-making means can be considered as the core of the CPS. Decision making tools form the optimal solution, which is the answer to the input information, and ensure its implementation. To date, there are many unresolved issues regarding the theoretical substantiation of the decision-making process in the CPS and the corresponding methods and means of their implementation. The search for theoretical and practical solutions for constructing decision-making tools is one of the most important when constructing the CPS in general.

To ensure the optimal operation of decision-making tools (DMT), it is necessary to develop a management system for it. Today, there is no theoretical basis for such developments for CPS, so the author turned to existing information about the development of control systems and, after analyzing the information received, developed his own approach for cyber-physics systems. Consequently, the development of such a system requires the study of the scope of the specific CPS, the appropriate methods and means of its implementation, the technical parameters of the components, possible reactions to external influences, internal states at different points of work, etc. Therefore, for the development of the control system of the DMT CPS it is necessary to carefully consider the principle of its operation, the methodology of the formation of decisions, processes, the structure of ensuring the formation and implementation of decisions, the usage of technical means and components. The work is aimed at highlighting a new approach to designing a control system for the DMT of the CPS.

II. ANALYSIS OF THE PROBLEM

CPS is a complex system that contains various types of components that perform a certain function according to the CPS [1]. The work of these components must be coordinated. The most difficult issues are:

- implementation of inter-level management,
- in-line management during work and transfer of information between components from the lower level (physical medium) to the higher level (user),
- control between components within each level.

The interaction of such a plan already exists through physical connections and corresponding logic. An open question remains the possibility of the CPS itself to make decisions about interaction with the physical environment or assistance in making the appropriate decisions by the user. Here, the complexity is manifested in the systematization of the information collected for the formation of statistical data. The next step is to transform the statistics into multiple models of possible solutions according to the user's request. Depending on the input data entering the CPS from the physical environment, decision-making means must form the most optimal response-response of the CPS in real-time. Therefore, the construction of an effective model of decision-making tools that implements these capabilities is one of the key issues in building a CPS.

Decision-making tools for CPS are intended for:

- formation of statistics
- the formation of response models,
- making decisions based on user requests;
- management of the implementation of the decisions,
- formation of the results of processing the characteristics of components of the physical world in real time.

In order to build decision-making tools (DMT), the DMT must clearly know the scope of the usage of a particular CPS. It depends on the specifics of the storage of statistical data and the methods of their processing precisely for the preparation of the decision-making process.

For storage and processing of data in most CPS it is expedient to use a self-learning system and elements of artificial intelligence that will help the user to make the best decision or perform certain actions on their own without user interference. Such a CPS adapts itself to changes in the physical world and can perform certain actions in the physical world. According to the basic principles of the DMT [4–8], it is advisable to store the statistics in the database, and the set of prevailing decision models is based on the models. The issue of communication with the user solves the intelligent interface.

- The control system of the DMT is of special interest to the user of the CPS. From the user's point of view, the management process itself must ensure:
- maintaining the structure of the system;
- support of working modes;
- realization of tasks, goals of functioning of these systems in conditions of various external influences and internal modes.

The need for decision-making and its implementation comes at the influence of the factors of the physical world on the CPS. Such factors can be predictable (predicted) and unpredictable. Therefore, DMT contain self-learning subsystems [2], so that the DMT has as many answers as possible through the DMT control system. In order to ensure that the CPS user management is sufficiently effective, the control system must satisfy the high level of the following properties:

- stability;
- security;
- efficiency;
- flexibility.

The stability of management as a property of the system to maintain its original state of rest or action under the influence of the environment on the CPS. To ensure sustainability, continuity of management, elimination of errors in assessing the state of the CPS, excluding delays in assessing the state of the CPS and the user's actions are important.

The security of the control system of DMT CPS is determined by its functional resistance to unauthorized actions.

The efficiency of the control system of the DMT of the CPS is characterized by the average duration of the decision-making cycle and its implementation in response to one type of environmental impact on the CPS. The smaller the duration of the cycle is, the more effective the system will be.

The flexibility of the control system of the CPS is determined by its ability to adapt to the changing environment and its effects. Flexibility is ensured by the application of appropriate algorithms (artificial intelligence, genetic algorithms, evolutionary algorithms, neural networks, etc.).

An effective control system is based on the following main components:

- information support of the processes of development and implementation of decisions;
- the set of standard procedures, functions, programs and specialized hardware modules for this CPS for the accomplishment of the tasks and objectives;
- preparing instructions for the user or users.

The optimization of these components leads to the improvement of the control system of DMT CPS. But it should be noted that, depending on the specifics of the usage of each CPS, these components can increase and take into account the specific requirements for the CPS.

Consequently, the control system of the DMT of the CPS must have a certain set of elements, subsystems and communication solutions between them, as well as the processes that ensure the specified operation of the CPS in general.

The purpose of the operation of the control system of the DMT of the CPS is to form and implement optimal decisions or to prepare the necessary information for making such decisions to the user in order to provide the necessary work-reaction of the CPS to achieve its tasks.

III. FORMULATION OF THE PROBLEM

At the moment, there are many developments in the development of decision support systems (DSS) [2]. Most of them are used by business executives in the decision making process, whose purpose is to help a person make the most optimal decision in a particular situation, relying on relevant statistics prepared by the DSS. Therefore, the principles of constructing DSS can be used in the construction of means of decision-making CPS, but taking into account the specifics of the usage of CPS.

The main tasks of this work are:

- to present the developed structural model of decision-making tools of the CPS using the basic principles of the DSS,
- to estimate hardware costs of decision-making tools of the CPS,
- to determine the main characteristics of the developed model.
- definition of the composition and content of the control system of the DMT of the CPS;
- determination of the property of the control system of the DMT of the CPS and the construction of its cybernetic model;
- definition of the basic parameters of the developed model;
- to demonstrate the developed cyberphysical system for recognizing objects from the video stream and draw conclusions about its characteristics and qualities.

The development of a structural model for measures for decision-making of ciberphysical systems

In order to address the development of decision-making tools of the CPS, it is first necessary to determine the management model at each level of the CPS and between levels in detail. The generalized structure of the CPS is given in [1]. The CPS has six levels and each one has its own methods and means of implementation in accordance with the specifics of usage. Each of these levels provides the appropriate processing and transfer of information, which is mainly managed automatically by the processes themselves within each level and between the levels to the level of IPR, where decision making is prepared on the basis of the information received from the previous levels. The general structural model of inter-level and intra-level control in the CPS is described in [2].

The number of blocks of intra-level control at each level depends on the system being developed. The following formula can be used to determine the hardware costs of the decision-making tools of the CPS:

$$A = Vij + Bc * i + Cn + Dm, \quad (1)$$

where A is the hardware cost of the decision-making tools of the CPS, i is the number of levels, Vij is the unit of intra-level control, Bc is the inter-level communication control unit, Cn is the means of decision-making, and Dm is the means of decision support.

The given model has the following characteristics:

- tree-like,
- hierarchical,
- interstitial-linked.

The following algorithm was used when constructing the general model of the structure of the CPS. Since the information is derived from the lower level (physical world) in order to bring it into the decision-making solution, it needs to be processed by means of collection and processing of the CPS. Each level has its own means of managing the transmission of information and its processing. But centralized it is going to the level of DMT. At the same level, the corresponding control information is automatically generated to respond to the CPS actions (Automatic Control Block) without user intervention (PMD). Or the user makes a decision, in accordance with the received recommendations from the DMT, with the help of the Block Management of PMD.

That is, the DMT contains two sublevels:

- means of preparation for decision making (MPDM),
- means of execution of the decision (MED).

In turn, the means of execution of the decision are divided into automatic and user-managed ones. The MPDM receives data from lower levels obtained through data collection, processing and data transmission. In [2] the structural model of decision-making means of the CPS is depicted. In turn, decision-making tools are a set of software tools, which includes a library of various decision support algorithms, a database of models, a database, control and auxiliary programs. The management program organizes the decision-making process. MPDM is used to support such activities in the decision-making process:

- definition of special tasks;
- the choice of a general strategy of actions;
- evaluation of results;
- initiating changes.

The structure of MPDM form the following main components [3]:

- database (DB);
- database management system (DBMS);
- Model Base (DM);
- Base Model Management System (DMMS);
- Intelligent interface with PMD.

The database contains information about the analyzed objects, and mathematical, logical, linguistic and other models are stored in the database, which are used for multicriteria, comparative analysis of solution alternatives.

In the tasks of constructing MPDM four basic varieties of their structures are distinguished: network, sandwich, ball, tower. The following factors influence the choice of specific MPDM structure:

- Integration of own DB with other internal and external DB;

- minimizing the waiting time for the response to a request;
- overcoming the difficulties in using large models;
- coordination of the dialogue with the base of models;
- reduction of the cost of building and maintaining the system;
- providing adaptive capabilities in the construction and development of MPDM.

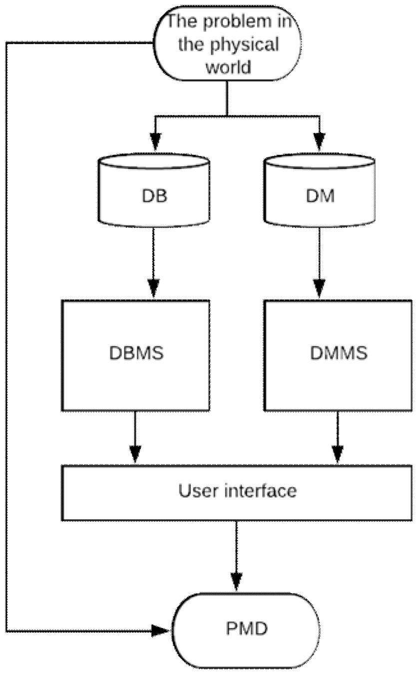

Fig. 1. DMT structure

Depending on the data it is working on, MPDM can be conventionally divided into operational and strategic ones. Operational MPDMs are designed to respond immediately to changes in the current situation. Strategic MPDMs focus on analyzing current and historical data collected from different sources and based on which models of optimal strategic decisions are built. Consequently, the overall structure of MPDM is depicted in Fig. 1.

Means of implementation of decisions – a complex of software and hardware that ensure the implementation of decisions made with the help of decision support.

Consequently, DMT is a multi-component system that contains:

- means of data accumulation,
- •means of intellectual analysis and data processing,
- means for forecasting or predicting changes in the physical environment,
- tools for finding an optimal solution when constructing a model of a corresponding CPS reaction to changes in the physical environment,
- means of implementation of the adopted decisions,
- means of displaying statistical changes in the physical environment.

IV. THE SYSTEM OF CONTROL OF DECISION MAKING MEANS OF CYBERPHYSICS SYSTEMS

Consider the pain of deeper means of solving the problem. Consequently, MPDMs receive data from lower levels obtained through the collection, processing and transmission of data. In turn, the DMT control system controls all of these components. Fig. 2 shows an extended structural model of CPS decision making tools.

From the user's point of view, the control system can be represented as a cybernetic control system model, which is the formalization of the CPS interaction, the DMT CPS control system and the physical world, as shown in Fig. 3.

As shown in Fig. 3, the CPS input is represented as a vector of input parameters x (t) for each time interval:

$$x(t) = [x1(t), x2(t), ..., xn(t)],$$

and is characterized by a set of all information that perceives the CPS from the physical world.

Output parameters y (t) for each time interval:

$$y(t) = [y1(t), y2(t), ..., ym(t)],$$

and are characterized by a set of all actions that perform CPS in response to the physical world.

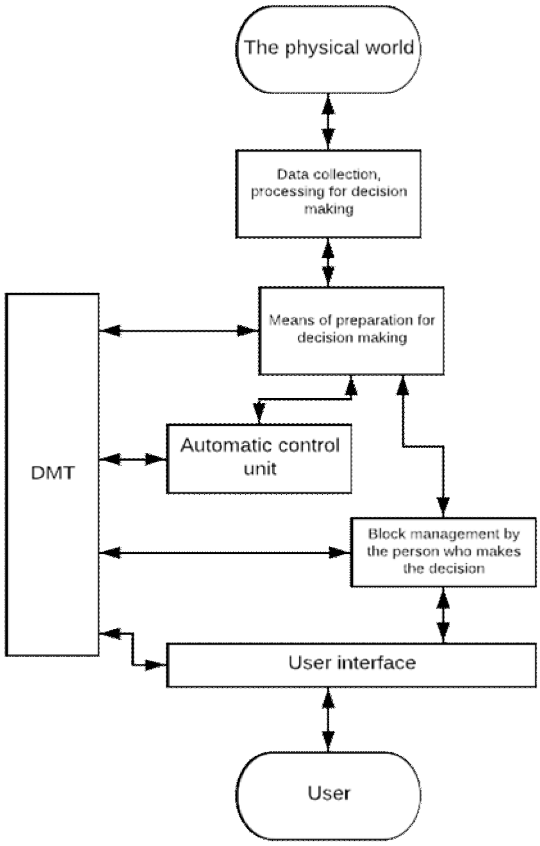

Fig. 2. Structural model of decision making tools CPS

The control of the control system describes the vector z (t), which depends on the input parameters and the set of internal states CPS v (t).

So, taking into account the above described dependencies, one can describe the management influence of the control system as follows:

$$z(t) = f(xi(t), vi(t)).$$

Then the output parameters CPS can be described as follows:

$$y(t) = f(z(t), k(t))$$

where z (t) is the control parameters of the DMT control system, k (t) is the random influence of the physical world on CFS at a given time.

Consequently, the DMT CPS management system processes a large amount of inputs for external and internal information, processes it using programs and specialized hardware modules developed for a particular CPS, and generates a set of control parameters. The control parameters start the CPS work depending on the input parameters obtained from the physical world, and the internal states of the system itself.

V. THE CYBER-PHYSICAL SYSTEM FOR RECOGNIZING OBJECTS FROM A VIDEO STREAM

Applying the above theory, the experimental cyberphysical system of recognition of objects (road signs) from video stream for car drivers was developed and tested.

It can be concluded from the collected data about systems for recognizing objects from a video stream, including road signs, namely Opel Eye, Speed Limit Assist, Traffic Sign Recognition, that these systems are difficult to access, are not easy to use and have only a certain set of Objects that can recognize. Also, some of these systems work only in certain vehicles or navigators, thus, these programs can not provide support for many drivers. So, to solve this problem, we developed a cyber-physics system for mobile devices on the iOS platform with a convenient and intuitive interface, driver voice message support and easy access to the system itself. This simplifies the driving process, improves road safety, avoids unpredictable conditions on the road, and can also serve as an indispensable assistant for beginner drivers.

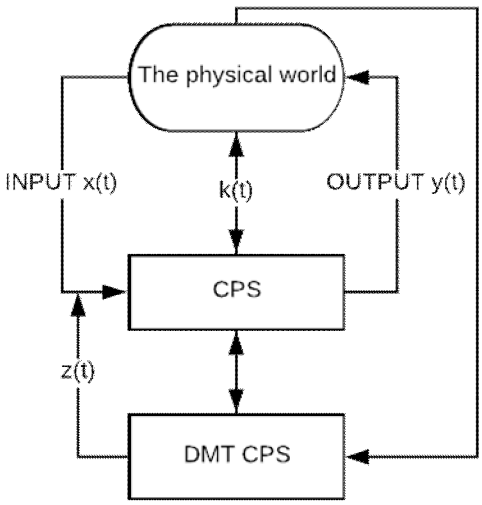

Fig. 3. Cybernetic model of the decision-making control system for CPS

In the process of developing a cyberphysical object recognition system (traffic signs) from a video stream, the iOS operating system was chosen because it has many benefits, such as a simple and intuitive interface, the system is quite secure, multitasking and with high speed. Also, the development environment is selected by Xcode, which Apple has developed to design software for iOS. The Realm mobile database is chosen which is faster and better than its analogues, besides, it is completely free, easy to install and is quite reliable. With a selection of software tools and for implementation, the well-known OpenCV library was chosen, which is an open-source computer-based library and contains over 500 functions capable of working in real time. It also contains the necessary algorithms for processing images, pattern recognition, video work, for tracking objects.

To implement this cyberphysical system, you need a mobile device on the iOS platform to test the system for recognizing objects from the video stream, as a result, selected:

- Iphone 5s
- OS: iOS 9.2.1.
- Built-in camera with 8MP module, f / 2.2 and Led flash unit. The video recording resolution is 120 fps.
- The Cortex A7 processor is used with 64-bit architecture, which provides high-performance video and photo processing.

The whole process of training the classifier is done using the ready-made console applications that are distributed together with the OpenCV library.

To study the necessary photographs of the subject in a real environment. The more similar the sample will be to what we want to recognize, the better the results will be.

Approximately 1.000 to 1.500 positive specimens and many negative ones are required for stable recognition. 150–200 positive images and 300 negative ones are used. The larger and more diverse the sample is, the more stable the worker and the longer the classifier learns. Then in Fig. 4 an example of a positive sample is shown.

Files for describing negative and positive objects have a different structure.

For a negative image file, this is just a list of relative paths to the images: Bad \ 1.jpg.

For positive-sampled files, the record is somewhat more complicated. In addition to the path, the position of the target object and its size must be specified. In principle, each positive image may contain several objects that are wanted:

Good \ 0.jpg 1 0 0 414 148,

where “Good \ 0.jpg” is the object address relative to the description file. “1” – the number of positive objects in the image. “0 0 414 148” – coordinates of a rectangle in the image in which the object is located. If there are several objects, then the entry becomes “Good \ 0.jpg 2 100 200 50 50 300 300 25 25”. The most convenient it is when one object is one frame, then the coordinates of the object are equal to the size of the frame.

It is learning that takes place in two stages. The first stage – all positive images are brought to the general format. This is done with the OpenCV utility called "opencv_createsamples.exe".

To create a pack of positive images let's launch opencv_createsamples through the console:

opencv_createsamples.exe -info Good.dat -vec samples.vec -w 30 -h 30.

where – info Good.dat – a file describing positive images. It contains addresses to images, vec samples.vec – a file in which the base of positive images is brought to the general format, w 30 -h 30 – the size of the template. You must display the proportions of the object you are looking for. For the used road signs, for example, the ratio is 1: 1. For numbers, the proportion will be 3: 1. To find pen or pencil, this proportion is 8: 1. The size of the template should be small, the longer the template is, the longer the training lasts.

The result of the program's operation is the file “samples.vec”, which will contain all positive images w * h sized, which will then be used by the decision-making control system of the given cyber-physics system at the time of recognition of road signs and the presentation of the corresponding voice and visual message by the driver.

For the formation of the final cascade, the utility “opencv_traincascade.exe” is used. This utility works for a very long time. The training of cascades for 150–200 objects takes 43 hours.

The decision-making control system of this cyber-physiological system interacts with the database. The database stores all positive search results with the advanced image processing data. Realm uses the History class to interact with the Realm model. It stores descriptions of road sign models that are recognized by the system.

In the case of a successful classification, the image will be added to the resulting array, after which the corresponding actions of the decision-making control system with the driver's message will take place, namely: a voice message and a visual display of the found characters on the screen (Fig. 6).

On the screen of your device, the driver sees an element of type UIImageView, in which the images received from the camera and processed by the classifier will be transmitted. Below, Fig. 7 shows the user interface.

In the case of identification of a road sign, the driver will see it in a picture, also on the screen, to the right, another element of the same type is placed, which is transparent by default. After having recognized a road sign, this item will display its image. In the lower left corner of the screen there is a button that allows the driver to open another UIViewController, which displays the history of successful search results, that is, a user in a UITableView type element can see the road sign and the time it passed by. Below, Fig. 8 shows a history of identities.

The entire user interface is powered by AutoLayout, which allows you to use this product on devices with different extensions, without losing the original look of the interface. Thus, we managed to implement a convenient and informative interface.

So, if we evaluate the qualitative characteristics of the developed cyberphysics system for recognizing objects from the video stream for road signs in general, then we can distinguish the following:

- client part as a mobile application based on the operating system iOS;
- the size of control images does not exceed 100 KB, which is a good indicator;
- use the camera of the mobile device;
- the system processor has been downloaded only 23 % when launching the developed mobile application (testing took place on the 6th version of the Iphone);
- the developed application is opened for 0.3 seconds, which is standard for applications of this operating system.

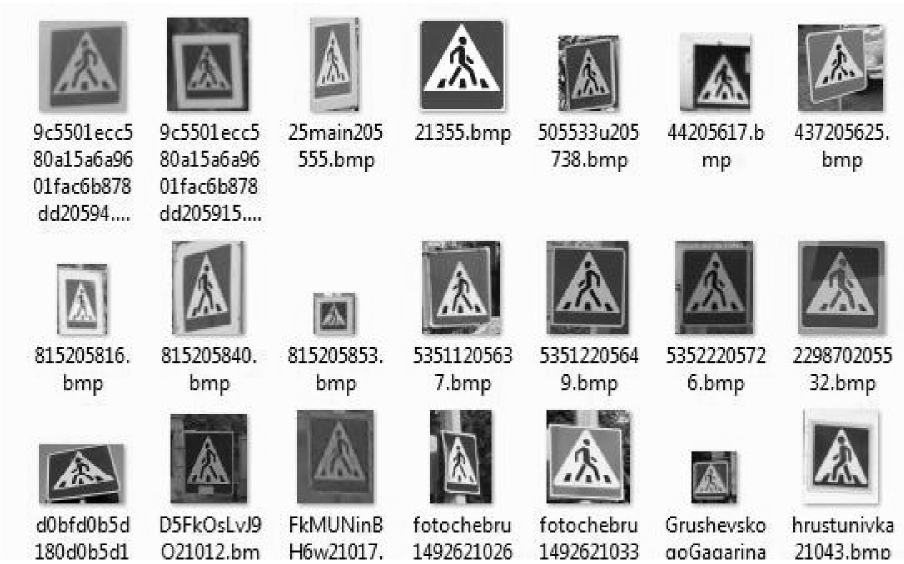

Fig. 4. The example of a positive sample

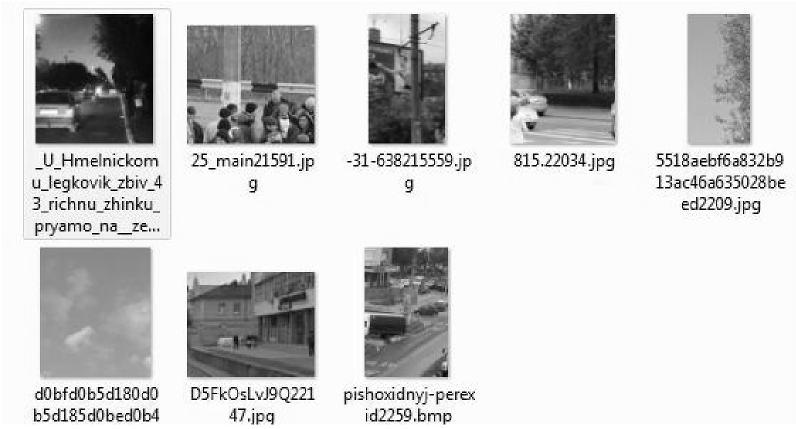

Fig. 5.The example of a negative sampling

Fig. 6. Visualization of the found signs

Fig. 7. Interface

Fig. 8. History of Identifications

The current experimental version of the cyberphysical object recognition system from the video stream allows you to recognize such signs as “crosswalk”, “give way” and “stop is forbidden” and provide the driver with a voice on a visual message regarding the corresponding sign. The results of testing the system showed a positive dynamics when recognizing road signs in real time, which confirms the history of identification. The decision support control system of this cyberphysics system controls the following stages of the work of the system: receiving an image from the camera of the mobile device, a road sign, and a driver's message.

Despite the rather long time of training (43 hours) of this mobile cyberphysics system, it makes sense to continue to increase the functionality of the control system of decision-making systems of this system in the direction of automation of work, namely: automatically through an on-board computer to adjust the speed according to the road signs to increase safety.

VI. CONCLUSIONS

In this paper, the main aspects of the development of decision-making and decision-making control systems for cyberphysics systems were considered. The problems of constructing decision-making tools and possible ways of their solution are discussed. The structural model of decision making tools is presented and the basic principles of its construction are formed. The basic characteristics of the developed model are given and the hardware costs for its realization are estimated. Also, a new approach to the development of a decision-making control system for cyberphysics systems is shown. The essence, purpose and properties of the control system are disclosed. A cybernetic model of decision-making control system is developed. The basic parameters of the developed model are described. Also, an experimental mobile cyberphysics system for recognizing objects (road signs) from a video stream for car drivers is presented.

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