Methodological Aspects for the Development of Information Systems of Unmanned Mobile Vehicles

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Abstract: In the work there is analyzed a process of developing and arranging information support systems of mobile vehicles with the enhanced autonomous level and fully autonomous. There are reviewed current trends in creating this sort of systems. In order to increase the effectiveness of processes of creating intellectual autopilots it is proposed to introduce into the review the space of similar systems configuration. The space axes are: sensors, models of environment, and algorithmic support. The points of this space are "assemblage points" of particular application systems. The configuration space enables to efficiently resolve the process of creating information support systems with the help of compliance matrixes, evaluate possible options of arranging the particular system. There are proposed solutions on components per each axis of the configuration space. As the basis for mobile means information systems the real time multifunctional vision systems and software-hardware unification is proposed. In terms of the hardware components, there are reviewed, in detail, arrangements of real time vision systems. The construction of external world models is proposed to establish on the interpreting navigation concept. In terms of algorithmic support, the combination of the split-level processing algorithms is proposed to implement based on large-scale frames and unification of software implementations. Examples of using the above-described approaches and solutions are presented.

1 INTRODUCTION

The peculiarity of robotics is integrity, integration of achievements of various fields of knowledge. The replacement of a person in his/her activities in the world around us requires the perception of this world and skill to move intentionally within it. The information support is an essential part of mobile and actually the main part of autonomous robots. The feature of robotics on the present stage is a shift from the purely scientific disciplines and narrowly specialized spheres of application into the more demandable means of reviewing technological and economical aspects of creating robotics systems (RS). The prevailing issues are reliability and economic efficiency of the systems being created. It is possible to determine two principle trends of creating this sort of systems. The first one (we guess, the dominating one) is the development/provision of needed transport infrastructure in which there is a motion of autonomous/automatic devices. The second trend is the intellectualization of autopilots. The main distinguishing feature is the effort to overcome the infrastructure disadvantages or complexities of external conditions at the expense of increasing capabilities of the on-board analyzer.

Up to now there are known a few projects of creating mobile robotics systems with the enhanced autonomous level. After the competitions in terms of purposeful motions of autonomous ground vehicles under the aegis of the US Defense Advanced Research Projects Agency (DAPRA) (Buehler et al, 2007, 2009) there have been activated works on creating commercial versions of similar systems. The well-known corporation Google since 2010 has been working on the project of "self-managed" light vehicle (Markoff, 2010). The US automobile company Oshkosh Truck Corporation has developed based on the heavy hauler a vehicle-robot (Defence Talk, 2006). The prototype of this vehicle participated in races DARPA 2004 and 2005. The US automobile company Ford demonstrated an autonomous Ford on the snow – driving in hard viewing conditions (on the practice ground in Michigan) (Ford Motor Company, 2016). Nissan

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(North Korea) based on the standard electric car Nissan Leaf is developing an autonomous vehicle which is passing field tests (Kadakov, 2015). Cognitive Technologies (Russia) in September 2015 notified about tests of autonomous KAMAZ on the practice ground in Naberezhnye Chelny (informed by Cognitive Technologies press-service), in October 2015 there appeared massages about tests of unpiloted KAMAZ on the practice ground in Noginsk (KAMAZ, 2015).

As examples of the most interesting non-commercial projects of unmanned mobile vehicles it's possible to name two US projects with more than ten-year history. NASA program of creating and using MARS rovers (1997 – present time) (Ellery, 2016). DAPRA program (USA) of creating unmanned flight vehicles, in particular, X47B project (lenta.ru, 2012).

The solution of tasks of information support of intellectual mobile RS requires the incorporation of scientific-technical achievements of such areas as applied mathematics, sensory, computer science, mechanics, control theory, artificial intellect, etc. About the complexity of tasks set in front of the developers of similar systems say the resources and the time dedicated by the developers to meet the target goals. The total cost of NASA and Jet Propulsion Lab project aimed at creating the MARS rover Curiosity Rover 2012 is estimated as 2.5bln USD. Such powerful companies as Google and Ford having more than a ten-year study experience join their efforts for the creation of unmanned vehicle (Automotive News, 2015). The Russian program of creating the unmanned vehicle is estimated as 300bln RUB. ROSAVTODOR is already spending annually 4bln RUB on the road marking for the unmanned vehicles (Alizar, 2015).

2 CONFIGURATION SPACE

In order to find way around a multidimensional space of problems when solving particular practical tasks of intellectual mobile robotics and determine the ways of forming technologies of development, we propose to structure the variety of the components of the information support systems (ISS) within control systems over such objects and make a review in the configuration space. Each axis of this space represents a plurality of possible solutions/arrangements of respective elements. Along one axis, there are sensors, along the second one there are view models of the environment, along the third one there are information processing algorithms. In the conventional cube of this space, it's possible to select alternative ways of collecting and processing information for the intellectual management over the intentional motions of mobile robots.

In the review we'll pay special attention to the unification of the software-hardware components as an important means of supplying reliability and economic efficiency of the proposed solutions.

2.1 Sensor Support of the Onboard ISS

The common list of means of sensor support systems of control over autonomous mobile objects at present is rather clearly identified. Shortly it may be characterized as follows. Traditional internal sensors of the mobile means plus sensors of external world. For the ground mobile vehicles such sensors are radars (as a rule, LIDARs), gyroscopes, accelerometers, satellite navigation systems and vision system (VS). VS is the one, "external" component of the information support system of the ground unmanned vehicles, which represents the principle interest of our review. For the unmanned vehicles in other spaces (air, underwater) this set kind of changes with account of environment properties (for example, ultra-sound detectors and side-scan sonars for the underwater vehicles, phased-array radars, radio and barometric altimeters for flight vehicles), but does not change the system-wide software-hardware ISS architecture of intellectual control systems. As a note, the characteristics of applied sensors are closely connected with requirements to the capacities of the onboard computers providing acquisition and processing of the respective data.

Analysis of the current state of the developments in the sphere of mobile vehicles ISS enables to identify such trends in the arrangement of mobile vehicles with sensor systems.

The priority issues of arrangement are those of complexation: all sensor systems; sensor systems of various ranges of radiant energy; 2D and 3D data.

VS of the visual, IR, radar bands in totality or separately become an essential component of intellectual autopilots.

We'll discuss in more detail the requirements to the most widespread and demandable VS type, i.e. visible range VS. We should note such specific requirements to video-cameras as part of VS of the contemporary mobile vehicles as:

- resolution (from 2Mb and higher);
- random access to raster units;
- signal output to the unified digital channel,

possible in various modes, but with obligatory mode “no compression”;

- responsivity/dynamic range;
- automatic control over the optical system stopping;
- external synchronization.

In order to assure requirements to the hardware/sensor devices when arranging the mobile vehicles ISS there is widely used COTS technology, i.e. method is well-known, well-proven for the arrangement of new highly-sophisticated complicated systems. In terms of sensory provision as means of gathering information about external world in real-time scale, there are well-proven 3D selective control detectors, in combination with visual data about the same spatial domain. As examples of such solutions we can indicate both which have become well-known Lidar devices (for “outdoor” application”), Kinect (for “indoor” application”), or similar, and author’s developments of VS with operated structured illumination based on spherical motors of direct control (Sokolov et al, 1995).

Universal computer based on IBM PC compatible architecture is the basis for integration of module solutions. We propose a computing control part of the real-time VS as the most resource-intensive, to take as the basis of arrangement of the computing part of the information support system of the intellectual control systems. Article 4 will provide examples of successful application of such approach.

2.2 Presentation of the External World in the Autopilot Information Support System

The problem of describing the external world in the computer presentation is not new and there is a range of approaches to its solution. The use of external world model in the onboard computer of mobile facility imposes additional constraints both on the computer capacities and on the real-time scale where it’s necessary to operate the model. Notwithstanding various studies in the area of external world simulation, we should state the absence of databases to store object-oriented data with the access in real-time scale.

Presentation about the external world in the onboard control systems of mobile vehicles is constructed with the use of the so called “navigation cross” (Figure 1).

When solving navigation tasks we take as the basis for the construction of external world model the interpretive navigation concept that has been developing since 80ies last century (Sokolov and Kirilchenko, 2015). The basis of the concept is made of following statements. As the presentation of knowledge about the external world there is used not a quantitative model in the absolute coordinate system, but a qualitative one as a sequence of interchange areas with same informative-visual contents. The model is formed as the information equivalence graph (IEG) This presentation serves a supplement and development of approaches of SLAM in the provision of goal-oriented motions of mobile vehicles in a weakly structured, unfamiliar environment.

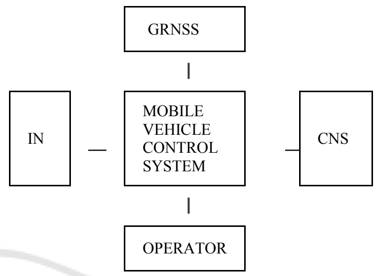

Figure 1: Diagram “navigation cross”, where GRNSS – global radio-navigation satellite system; CNS – conventional navigation system including processes of reckoning and adjustments by reference points; IN – interpretive navigation.

The arrangement of the external world model as IEG is cost-effective with regard to the computer capacities and enables to unify the motion planning stage independently from the level of highlighting the reference marks in the surrounding environment.

In the software implementation of the external world presentation there is used a unified instrument tool to work with the graphs. This structure implements polymorphism during the work with various structures. It uniformly operates with feature descriptions of the landmarks, circles and belts of the landmarks, areas of the information equivalence, anthologies of the textual description of scenes and sets of visual data processing algorithms.

The movement control language in the mode of tele-programming based on interpretive navigation is more natural for the communication of the operator and unmanned transport vehicle as it applies “the commonly-accepted” logics of explaining the route based on dynamic pattern in the process of movement along this route of visible descriptions of the environment based on the reference marks.

The issues of unified presentation of the environment model are on the stage of elaboration and reaching the technological solutions.

2.3 Algorithmic Supporting

When reviewing the main issues of the vision system in the current intellectual autopilots and determining the main requirements to them, there are defined the most specific groups of algorithms of detecting and identifying objects on images. For the criteria of the algorithms quality, it is proposed to review robustness, localization, and computing implementation, in particular, with such a characteristic as the number of operations per pixel in-process. The effectiveness of performing these requirements depends on the selected technology of receiving and preliminary processing of the input information about the observed object space, applied structure solutions and algorithms of transforming information showing the observed object space into the applied model. All this in totality determines the main characteristics of the system, such as persistence, validity of recognition, accuracy of performed actions, and technical feasibility.

There are determined ways of satisfying requirements to the algorithmic supporting of the intellectual mobile vehicles: rational data selection; effective processing; hardware implementation; sensory systems integration of ISS; unification of software solutions.

The above ways are shown in the software-hardware architecture. In particular, in order to implement low and intermediate algorithm levels the following hardware facilities are widely applied:

Multi-core general processors (Sokolov and Boguslavsk, 2011); GPU (Vasilyev et al., 2011); other special video-processors; FPGA;

Combination of the above-listed (Krasnobaev, 2005)

Review of the available publications and conferences' documents shows that some computer vision tasks have been brought to the stage of technological solutions, i.e. known combination of algorithms of visual data collection and processing. Results of the recent software surveys (Laplante, 2004; Rankin al., 2011; Hillel et al., 2012; Tumofte et al., 2014) enabled to activate and extend the VS application in practical robotics tasks. There are works proposing metrics for the quality evaluation of the real time vision systems (Baranov and Telezhkin, 2014; Baranov and Nikiforov, 2015). Practical possibility of using stereo-systems in real time scale has been justified (Wagner et al., 2002).

The above achievements in the area of algorithmic supporting leave open a question about the technology of complexing the algorithmic supporting of particular application tasks.

2.4 Proposed Implementation of Algorithmic Supporting

Distinctive features of the proposed approach to the formation of the software for the information support of unpiloted mobile vehicles are as follows:

- Provision of possibility for the cross-platform development based on universal PC and high-speed carry to the special computing platforms at the expense of division of the software into the set of interacting parallel subsystems.
- Specialization of the original VS programming frame at the expense of extension within the developed software architecture for the interaction with external subsystems of unmanned vehicles.
- The extended subsystem of processing visual data from a few point of view assuring the real-time processing of video-sequences from high-resolution visual sensors.
- Use of reusable components to process the visual data for the prototyping of software being developed.
- Implementation of special debugging tools to assure the reproducibility of the software operation on the development and testing stage.

Fig.2 shows unified structural units of the VS frame.

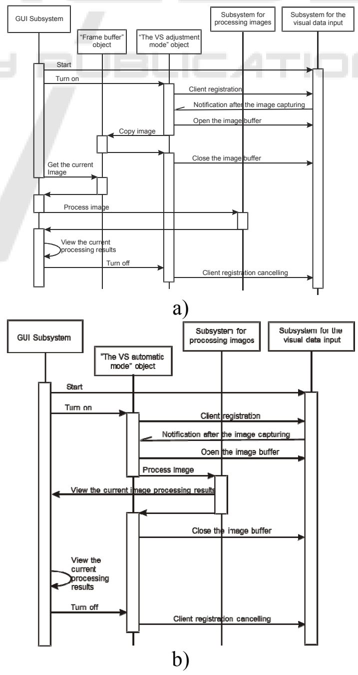

Figure 2: Unified structural units of the VS frame: a) – system setup mode; b) – automatic mode.

Implementation of all algorithms included into the software frame are supplied with characteristics of performance time on some or other hardware support tools.

Direct analogs for the software as functional frame and set of typical modules for unmanned and semiautomatic vehicles are not available. Some solutions from related subject area are known.

- Functional libraries implementing algorithms of processing images and computer vision (OpenCV, LeadTools, HALCON) do not contain full applications and implementations of the application level architectures.
- Rapid application development environment to process images (Matrox Assistant, National Instruments LabVIEW) are aimed at industrial automation tasks and use of closed software-hardware platform. They are not available on the level of initial texts and do not enable to control the functioning of the application in real-time mode.
- Prototypes of algorithms (extension packs MATLAB) are aimed at adjusting some algorithms which require the transfer or repeated implementation for the use in the target application.

The described tools are good on the stage of the very first surveys, but during the shift to the technologies of implementation from these surveys to the onboard means there is a big distance that may have hard obstacles such as real-time scale requirements and coherence of all components.

In comparison with all above-described solutions, the proposed software system simplifies the design and incorporation of information systems based on visual information processing at the expense of using the worked-out software components and expended software model (Sokolov and Boguslavsky, 2011).

2.5 ISS Arrangement Scheme

Here-below there is an approximate mobile means ISS arrangement scheme of the intellectual mobile robot to solve a specific task.

The arrangement process is iterational.

1. Wording of the formalized description of a task in the language of object description, external world (target environment) and necessary actions (transformations) with the objects in its state space. (The efficient approach of this arrangement stage is a proven method of constructing anthologies of the subject field).
2. The external world model is being formed.
3. There are selected hardware sensory tools assuring the receiving of needed initial data (to form the external world model).
4. There is formed a set of algorithms for the information support of solving the goal-oriented task.
5. Testing of capability of finding/reaching all above-listed components and calculation of the possession cost.
6. Definition: arrangement is acceptable? If yes, the process is completed; if not, the transfer to the next iteration (steps 1-5)

For a quantitative estimation of MV ISS configuration process quality it is possible to use deviation size (Δ) of current ISS configurations from system of requirements / the technical project. This size is defined by the function of the coordination depending on matrixes of conformity in planes of configuration space. In the described initial stage of researches linear function of the coordination was considered $\Delta = X - W \Sigma \alpha_i R_i$, where: X - a set (tuple) of variables of the configuration space meeting requirements to packed ISS; R_i - a conformity matrix; α_i - importance factor; W - a matrix of the dimension coordination.

3 EXAMPLES OF IMPLEMENTATIONS

We'll enlist a few examples of using the above-described unified software in tasks of mobile vehicles information support.

<u>Control over railway infrastructure objects.</u> Railway infrastructure objects are quite different and need a regular state control. Vision systems are widely used in the mobile control facilities. They help to collect data, and the results of control are formed in the deferred analysis. We proposed intellectual mobile modules which enable to process the visual data «on line" (Sokolov et al., 2012). The above-described approaches permitted to shortly solve a few control tasks of such railway infrastructures as position finding of the contact wire heightwise and on the map, determination of interacting force of the contact wire and pantograph; control over realigning of rails, inspection over the shoulder of ballast section and other additional parameters of the track structure. All measurements and control data are fixed to absolute (GIS and GPS/GLONASS) and relative (route) coordinates.

Implementation of the algorithmic supply on three general-purpose computers with Intel Pentium 4 2.4 GHz processor enables to inspect objects in one field of view at speed up to 250 km/h.

Automatic monitoring surveillance system of approximation and docking processes of space crafts and ISS. One of the most important stages of the space craft flight is their approximation and coupling. Based on the visual data there has been developed Automatic monitoring surveillance system of approximation and coupling processes of space crafts and ISS. The system enables to determine, in automatic mode, parameters of relative movement of space crafts and ISS, analyzes their compliance with the permitted values and shows information in a way acceptable for the perception by the person-operator or automatic control system (Boguslavsky et al., 2004).

Night vision system to help the driver. VS based on thermal camera analyzes environment in front of the moving vehicle and provides information about the vehicle position with regard to roadway, warns about possible traffic obstacles such as other vehicles or pedestrians. The system mock-up showed good results both in urban environment and on country roads (Sokolov et al., 2008).

The implementation of algorithmic supply on one general-purpose computer with Intel Core Quad 2.4 GHz processor enables to acquire appropriate information at speed up to 90km/h.

VS as part of mobile laboratory for online diagnostics of road surface. VS to control the state of the toad surface is intended to check wheel tracking, cracks, holes, defects of road marking. VS consists of looking-forward video-camera and three cameras with structured lighting. All results of visual data processing are integrated with GPS/GLONASS data about the positioning of mobile laboratory and electronic route map (Sokolov et al., 2012).

Implementation of the algorithmic supply on three general-purpose computers with Intel Core i7 2.4 GHz processors enables to inspect the road surface at speed up to 120 km/h.

VS as part of mobile complex of operational mapping. VS task as part of mobile complex of operational mapping is putting, on the electronic map, objects located along the route of the mobile complex. Besides VS, which consists of two stereo-pairs, the complex includes GIRS, satellite navigation system, odometer, and program making e-maps. Data from all the subsystems are integrated for the precise location of the objects found within view. Some objects are identified and recorded into GIS in automatic mode (road signs and other known engineering facilities), some other part is fixed in semiautomatic mode with the operator's involvement (Sokolov et al., 2011).

The implementation of algorithmic supply on three general-purpose computers with Intel Core i7 1.8 GHz processors enables to make operational mapping at speed up to 60km/h.

Unmanned flying vehicle VS as part of the onboard navigation equipment for piloted and unmanned flying vehicles. Based on the VS development of the ground mobile vehicles there is formed a VS software-hardware architecture for information support of automatic movement of a flying vehicle on the runway, take-off and landing. On the VS mock-up there have been obtained assessments of accuracy characteristics of the system. Experiments with the mock-up as part of the flying laboratory confirmed a possibility of successful application of the vision system as part of supplementary independent information channel for the provision of automatic control over the flying vehicle when moving along the RW, take-off and landing (Sokolov et al., 2015).

4 CONCLUSION

There have been reviewed trends in creating information support systems of mobile vehicles with the enhanced level of autonomous and fully autonomous. It is stated a shift of mobile robotics from the rank of purely scientific disciplines and narrowly-specialized fields of application into the rank of more demandable tool of solving a wide range of tasks of human activity. Vision systems occupy the first roles in systems of information support of mobile vehicles. In order to increase the efficiency of processes of creating intellectual autopilots of the mobile vehicles and to reduce a price of the autopilots it is proposed to introduce for the review a configuration space of such systems. In this space, it is proposed a methodology of arranging the information support systems of the mobile vehicles with the real-time vision systems as central part.

On the basis of generalization of requirements to hardware and unification of VS software architecture and its realization in the form of software framework the universal architecture of systems of autopilots information support is generated. Examples of economically expedient solution of applied problems of land, air and space application with use of the described technique are resulted. In the meantime, a wide range of questions still needs their settlement. This is also a construction of more distinct metrics on the axis of the proposed configuration space and construction of matrix of the components of information support systems compliance, and some others. The solution of the specified problems makes the program of the further works of our group.

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