"Unmanned vehicle systems in unstructured environments: challenge and current status"

V. Gradetsky, M. Knyazkov

Ishlinsky Institute for Problems in Mechanics RAS (IPMech RAS)

gradet@ipmnet.ru

Abstract

The scientific and applied interest to Unmanned vehicle systems (UVS) or Unmanned guided vehicles (UGV) is growing every year and a lot of world-known universities and companies are working very hard in R&D of UVS. The fully autonomous vehicles or ones with different degrees of autonomy vehicles are used on the land, in the air, and in the sea for broad range of technologies including hazardous waste cleanup, agriculture crops processing, transportation, underwater monitoring, nuclear power station repair, as well as security, inspection, demining, military operations.The new uses for these systems may be found every day.

Real UVS has to understand control commands fast and without mistakes. They have to possess logically thinking, have possibilities of learning and training, produce decision making by themselves, to move in unknown environment without operator. However, today in practice the situation may arise when operator forced to intervene in teleoperated control because of unsufficient reliability of robot behaviour. High level of artificial intelligence and mind as well as data base and special software are required for real UVS.

Introduction

As a rule UVS includes following systems: mechanical, sensory, control, drive, transdusers of external information, technology. The systems are acting in accordance with solving tasks, algorithms, programming trajectory of motion, what may be proofread automatically depending on environmental situation changing.

The brain of UVS is intelligent cooperation of environment by means detective sensors and multilevel feedback control, working under special software and algorithms.

Software is used for such functions like communications, data links, vehicle sensory control, and data management. Various UVS software challenges are illustrated as example of company development, including software architecture and data collection, transfer, integration and decision-making [1-3].

Flexibility, configurability, reliability and availability are important for UVS software.

Artificial intelligent planning, logical kernels based on "Multidimensional Information Variable Adaptive Reality System" presented by several companies may serve as an example of robot software. Several types of UVS including Wall Climbing Machine, illustrate their possibility for various functions and tasks [4-7], depends of areas applications (Fig. 1).

Dron quadrocopter

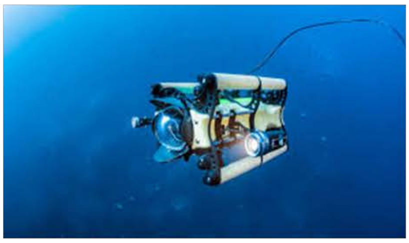
Autonomous Systems, Control and Optimization (ASCO) Lab

Ground robot

MAARS: The MAARS (Modular Advanced Armed Robotic System)

Caterpillar robot

CFP Robotic Group - CFP Company



Underwater robot

Pure Advantage

Robot car

Google car

Wall Climbing robot

IPMeh RAS

Fig. 1 Air, ground, underwater, fields Robots.

Sensory and navigation systems are rather important for UVS; among these it is necessary to mention laser scanner, vision and stereo vision, optical zoom cameras, GPS/GLONASS, etc., that are used for trajectory planning, obstacle avoidance, recognition of objects, 3D vision, design of maps [8-14].

Different control methods for UVS, strategies of autonomous wheeled mobile robot motion in unstructured environments, including fuzzy system, neural computation are analyzed and conditions for performing tasks realization are considered. Groups of mobile robots motion are based on artificial intelligent application.

Creation of artificial brain in machine areas permits to increase reliability of multiagent motion for robot interaction. Information and data transmission is important for providing the required direction of motion for every agent. Information of motion and map correction data are storing in the memory of every robot. To know mutual agent position, all robots have wireless radiofrequency sensors. Multiagent systems have possibility for adaptation to environment.

The future R&D will improve main peculiarities of UVS and multiagent group. Among the noticed characteristics there are reliability, maneuvrability, accuracy, stability, and increase functional possibilities.

Future aspects of UVS innovation technologies, their application, improving of people live are taken into consideration.

UVS Structure

The main peculiarity of UVS is that their can perform intelligent motion in unstructured environment with possibility to fulfill decision making. Mobile robot motion is accomplish automatically by means intelligent control without people or with minimal participation of man-operator on the highest level of control structure.Degree of autonomy are determined on possible participation and role of man-operator. UVS is acting (Fig. 2) under sensory control based on special software and algorithms using such functions as artificial intelligence, decision making, obstacle avoidance that is realised by application fuzzy logic, neural computation that could satisfy such qualities like reliability, manoeuvrability, easy connection, stable motion on undetermine environments. UVS may be equipped by ultrasonic sensors and stereovision system. The autonomous mobile robot has groups of ultrasonic sensors to detect obstacles in the front, to the right and to the left of the vehicle that the model of the mobile robot has two or four driving wheels and the angular velocities of the wheels are independently controlled.

The proposed methods have been implemented on the sensory-based control strategy. UVS for use on land can solve various goals (Fig. 3) and trajectory planning has important significance for motion design.

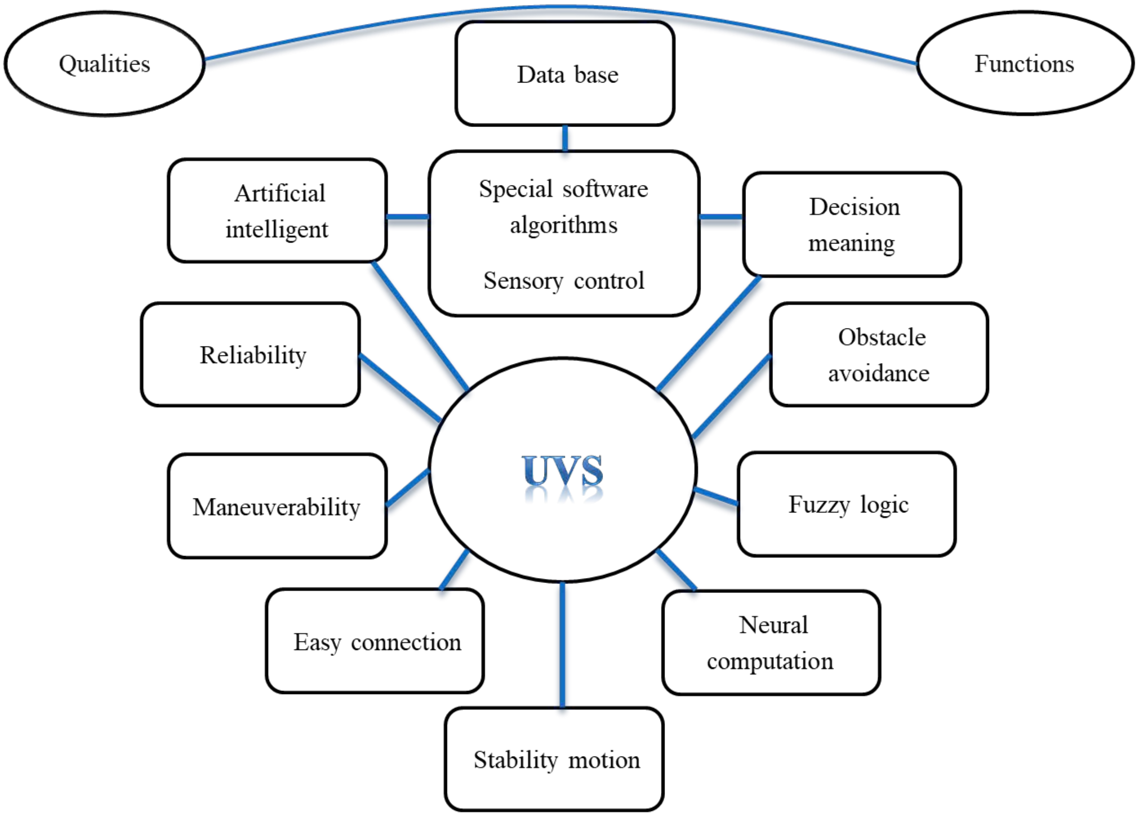


Fig. 2 Unmanned Vehicle System (UVS) Structure.

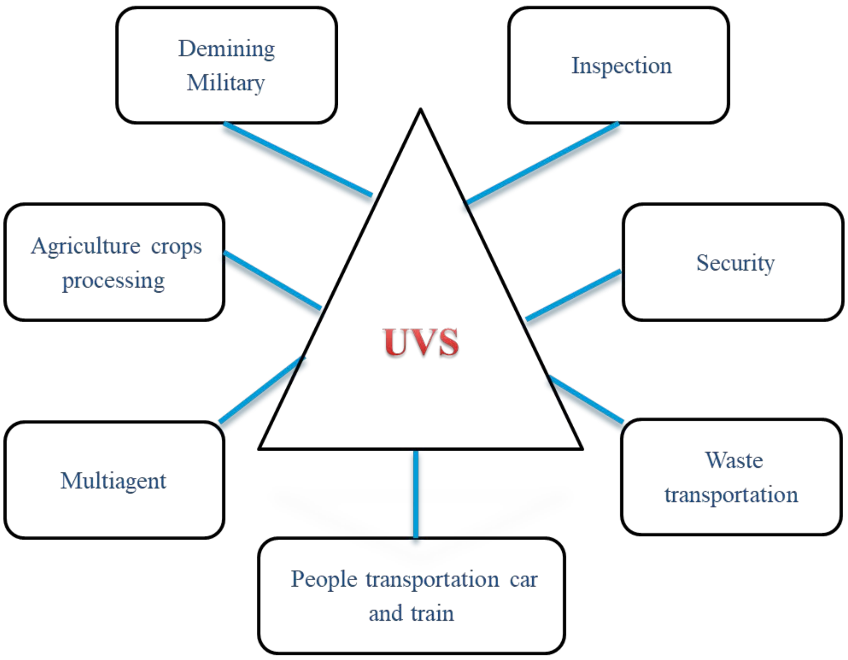
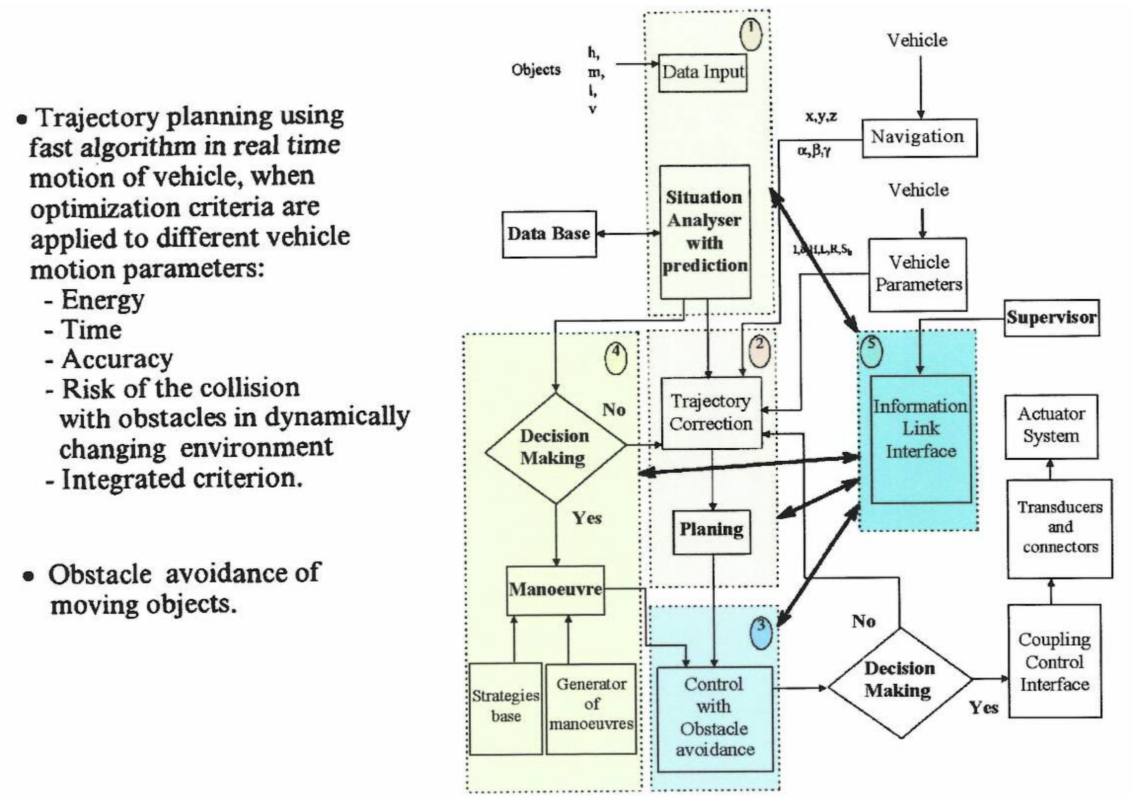


Fig. 3 UVS for use on land.

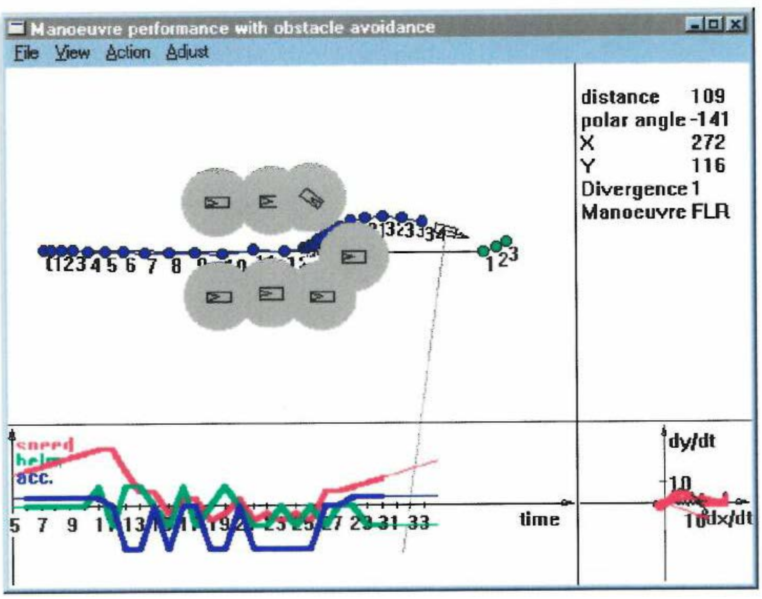
Trajectory planning.Fuzzy logic.Decision making.

In common case structure of the trajectory planning with obstacle avoidance is presented in Fig. 4 and it includes 5 blocks:

1 – situation analyzer with prediction, 2 – trajectory correction and planning, 3 – fuzzy control with obstacle avoidance, 4 – decision making and manoeuvre producing, 5 – information link interface.



Structure of the trajectory planning with obstacle avoidance



Computer simulation of obstacle avoidance manoeuvre in trajectory planning.

Fig. 4Trajectory planning and obstacle avoidance.

Example of computer simulation is showing obstacle avoidance with manoeuvre in trajectory planning processes (Fig. 5).

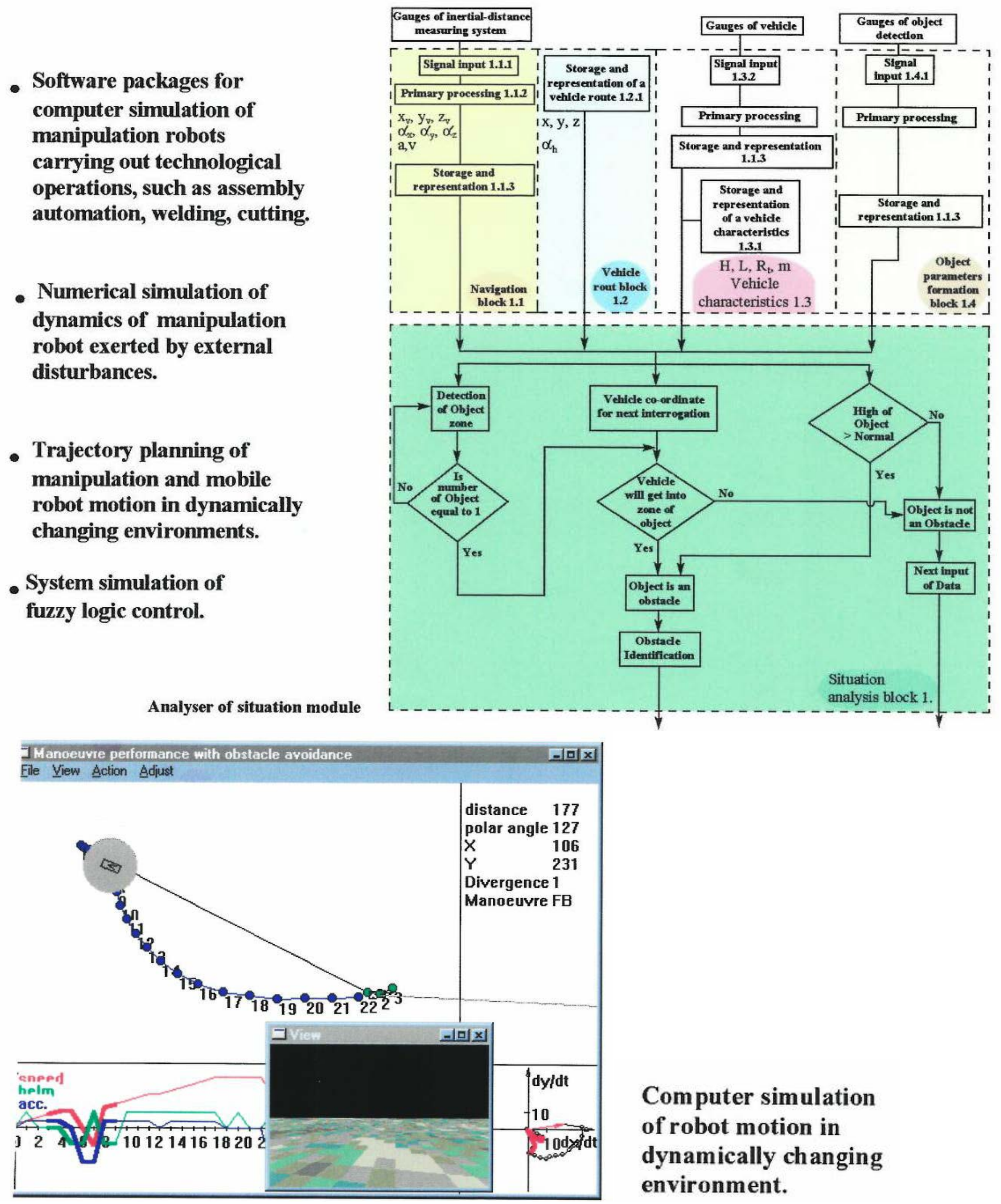


Fig. 5Computer simulation of robot dynamics.

Fuzzy logic for decision making was suggested in paper [1] and was applied for car algorithmic control of a model car by oral instruction [2] and for design control system [3]. Fuzzy systems on the base of Weight Associative Rule Processor WARP were created and methods of realization of such system was delivered [4-7].

Currently much research in robotics deals with different problems of the motion of wheeled mobile robots and the motion control of wheeled mobile robots in unstructured environments. Fuzzy logic approaches to mobile robot navigation and obstacle avoidance have been investigated by several researchers. Many application works of fuzzy logic in the mobile robot field have given promising results.

Strategy was presented in paper [11] for the autonomous navigation of field mobile robots on hazardous natural terrain using a fuzzy logic approach and a novel measure of terrain traversability. The navigation strategy is comprised of three simple, independent behaviours: seek-goal, traverse-terrain, and avoid obstacles. This navigation strategy requires no a priori information about the environment.

The sensor-based navigation of a mobile robot in an indoor environment is very well presented in [12]. The paper deals with the problem of the navigation of a mobile robot either in an unknown indoor environment or in a partially-known one. Fuzzy controllers are created for the navigation of the real robot. The good results obtained illustrate the robustness of a fuzzy logic approach with regardto sensor imperfections.

The fuzzy reactive control of a mobile robot incorporating a real/virtual target-switching strategy has been made in [13]. Real-time fuzzy reactive control is investigated for automatic navigation of an intelligent mobile robot in unknown and changing environments. The reactive rule base governing the robot behavior is synthesized corresponding to the various situations defined by instant mobile robot motion, environment and target information.

Paper [14-17] presents a control method for the formation on nonholomic mobile robots. Robots track desired trajectories in the environment with static convex-shaped obstacles. The algorithm includes collision-avoidance between robots and obstacles.

In many papers, for example [18-23] fuzzy control and the other methods are applied to the navigation or reliable motion of the autonomous mobile robot or wall climbing robot in unstructuredenvironments over surfaces with obstacles and slopes.

On the base of fuzzy logic and neurone network theory the algorithms for fuzzy control and decision making are developed to promote the vehicle motion in unstructured environments. Mathematical models of fuzzy control are studying to represent he real dynamic scene motion, using cognitive graphics. In the simulation process the optimum motion parameters are chose under different requirements, restrictions, forming environment scenes and adequate information about environment and vehicle motion. The problems of modelling and control are solved for different customer demands.

On the base of fuzzy logic approach the trajectoryplanning system is developed for the vehicle motion on dynamically changing environment with obstacle avoidance, when the obstacles could move independently. Thedirection of the vehicle motion may be changed automatically depending on surrounding situation. The pattern recognition of the obstacles is produced under robot motion. Software packages for computer simulation are carried out.

Interactions between man, robot, machine and environment are studying and various intelligent interfaces are created for interactions between man and environment, such as: “man-robot”, “man-environment”. For example, “man-robot” computer interface provides a friendly co-operation between people and robots. Situation analysis is provided the decision making process, robot teaching, trying and errors method.

The fast and sophisticated algorithms were created for trajectory planning problem solving for a mobile vehicle in real time motion. The numerical calculated optimised vehicle motion was considered under satisfaction of main motion parameter criteria, such as minimum energy, minimum time, minimum risk (maximum safety), maximum accuracy and integrated criterion. Trajectory planning considered to avoid the obstacles, to produce the manoeuvres, to avoid the collision, to realise the requirement task under motion on dynamically changing environments and on nonpredicted situations in advanced. Special control algorithms are suggested for correction the programming motion depended on suddenly situation changing. Fuzzy control method developed for these kinds of tasks with the possibility to produce the primitive decision making in the motion with maximum permitted velocity.

Examples of UVS

Examples of air robot and micro robot for space presented in Fig. 6 and Fig. 7.

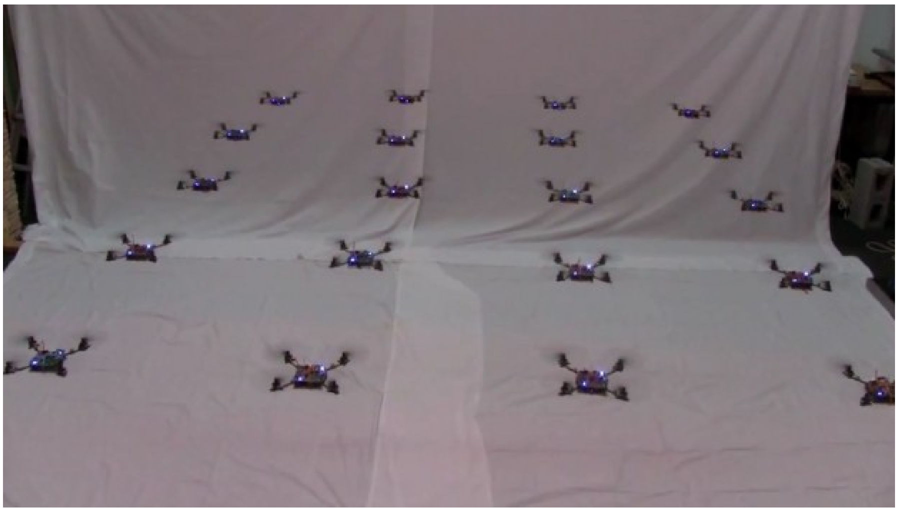


Fig. 6 Air robots.

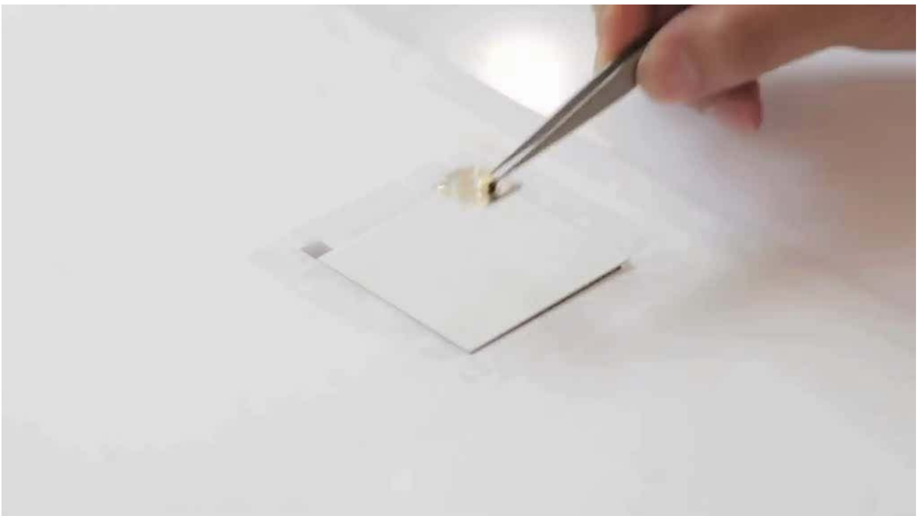


Fig. 7Micro robot for space.

UVS for use on the land may accomplish various functions. Mainly there are intended for transportation people and payloads as usually cars or train. Another part includes special UVS application for special purposes like security, patrol, multiagent system, inspection, agriculture, demining, military andextremeconditions as nuclear power station service and repair.

Many companies (Google, BMW, Toyota and others) are presented autonomous cars moving without drivers, as example may be presented Toyota Prius, Lexus (Google), Piaggio Porter (UK), TerraMax (Oshkosh Corporation and VisCab). In 2011 Airport Hitrow made announce about using ULTra UVS for transportation passengers between terminals.

In March, 2012, (Nevada, USA), stepped in law that permitted riding along highway or main road for cars using artificial brain, sensors and global positioner system for motion independently without active intervention of man-driver. Driver is called as operator in this case, for possibility to control namely the robot but not car. Laser on the roof of Toyota UVS car intended for navigation instead of eyes. Specialists from “Google” consider that intelligent cars will move along roads after 4-5 years. Approximately 20 years ago was start for intelligent cars R&D.

Such optimism is rather excessive but success is sensitive because cars without drivers were moving many thousand miles along roads of Europe, America, Asia. Data about road situation contain in power board computer where decision making and control of car are produce. At the same time more than ten microprocessors intended for engine, breake and other system of local control.Sensors about pressure in the wheels, temperature of oil and cool systems, and other parameters. The problem with parking is solved also by help of multipurpose technology “drive me” (Google Piaggio Porter Companies, Vislab Labs, Darpa cars Terra Max, MIG) (Fig. 8, 9).

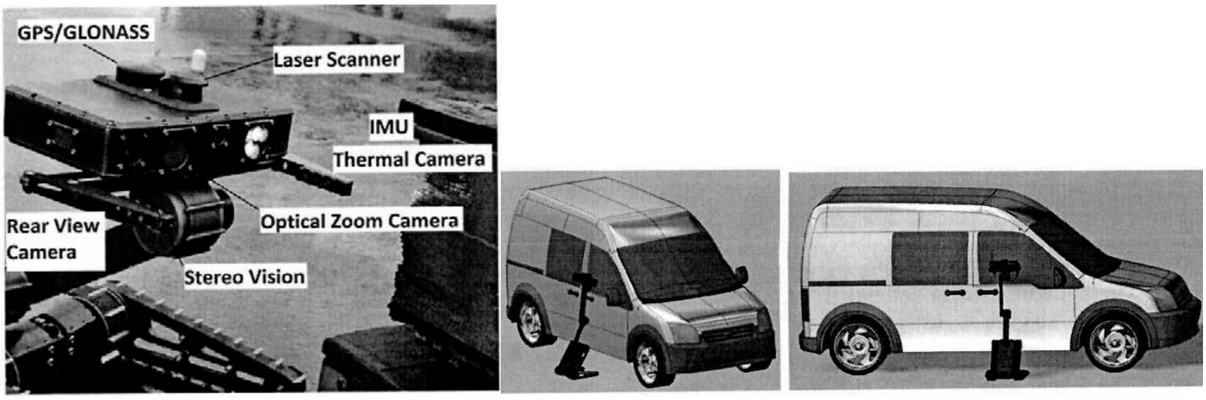


Fig. 8Sensors on board the robots.

Fig. 9Sensors on board the car.

Ground UVS special type

As example of special robot type, it is possible to note Mobile robot for extinguishing fires (Fig. 10).

Fig. 10 Mobile robots for extinguishing fires.

Robot Tral Patrol (SMP Robotics) intended for guard various unfrequented territories and dangerous objects by means of automatically moving using program trajectory. It can ptotect such objects like stores, plants, works, parkings, etc. by moving on day and night time.

A lot of designed mobile robot has dufferent degree of autonomy, when majority of operations are realized without man but final decision formulate man-operator.

Mobile robots easy, middle and heavy classes are intended for fire-fighting purposes, dangerous situations, underground applications (Fig. 11- 13). Robot can be used in dust, snowing, rain conditions. Robots are equipped with sensory systems.

Fig. 11 Multifunctional vehicle of fast response for fire-and-saving operations with the use of the mobile robotized complex of the easy class.

Fig. 12 Mobile robotic complex of the middle class "EL- 4".

Fig. 13Mobile robotic complex of heavy class "EL-10".

These are many examples of effective UVS application with possibility to partially control of man-operator. Examples of such system may be mobile robot "All-Terrain TM5" (Vezdehod TM5) (Fig. 14).

Fig. 14Mobile robotic engineering complex
«VEHICLE TM5».

The robot intended for inspection of sparsely populated environment, detection of mines dangerously explosive loading in containers. Technical characteristics: mass – 50 kg, working time – 2 hours, distance – up to 600 m, velocity – up to 1,0 m/s.

"Berloga R" robot intended for radiation and chemical inspection of undetermined environments. Find decision andremote control of such system is produced by radio (Fig. 15).

Fig. 15Remote controlled robotechnical complex of radiation and chemical intelligence «BERLOGA-P».

Inspection machines for work at nuclear power plants (NIKIMT, Russia) is presented in Fig. 16.

Fig. 16Inspection mobile robot for work at nuclear power plants (NIKIMT ITUTSR, RosatomStroy).

Wall climbing robots (WCR) contain determine type of UVS with limited area of autonomy. There are used in such extreme conditions asdesactivation inspection and repair in nuclear power station (Fig. 17, 18) Another WCR application is fire-fighting operations on the inner surfaces of big reservoirs with petroleum. Main motion and manoeuvring of such mashines are realized automatically but final decision-making is controlling by man-operator. Decision making and strategy of underwater wall climbing robot is shown in Fig.19.

Fig. 17Wall climbing robot.

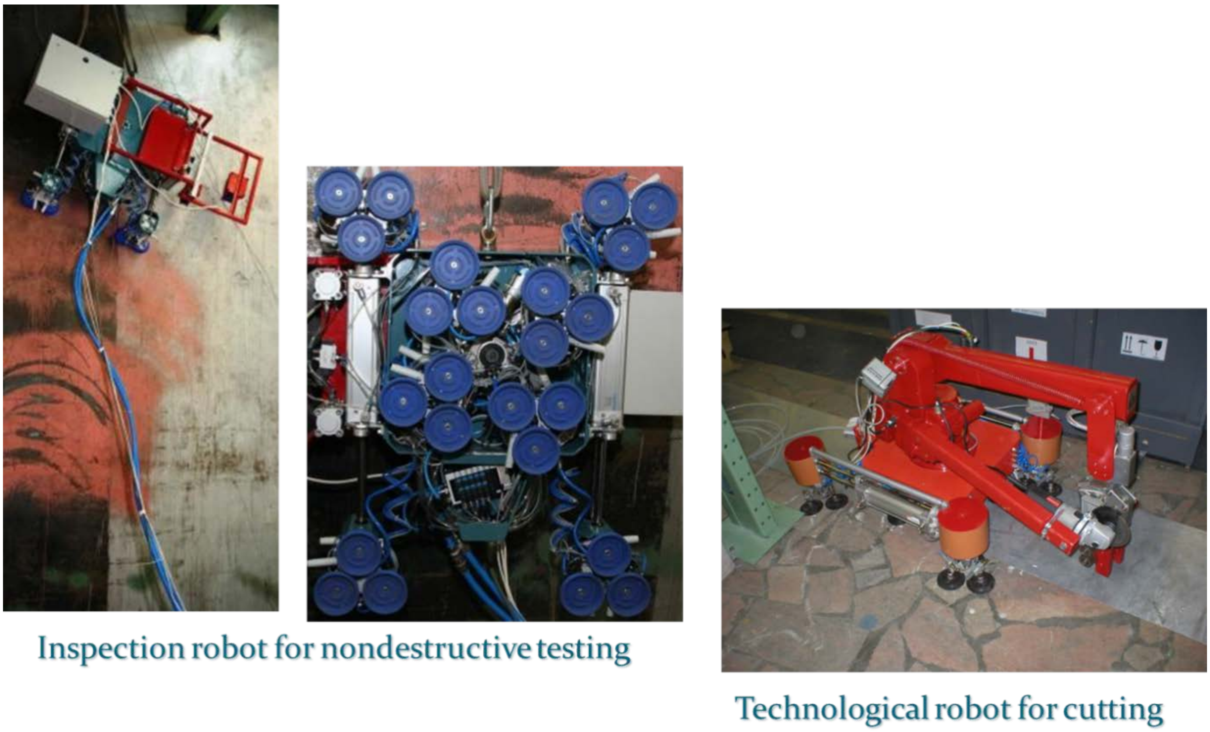


Fig. 18 Wall climbing robots for deactivation, inspection and repair in nuclear power station.

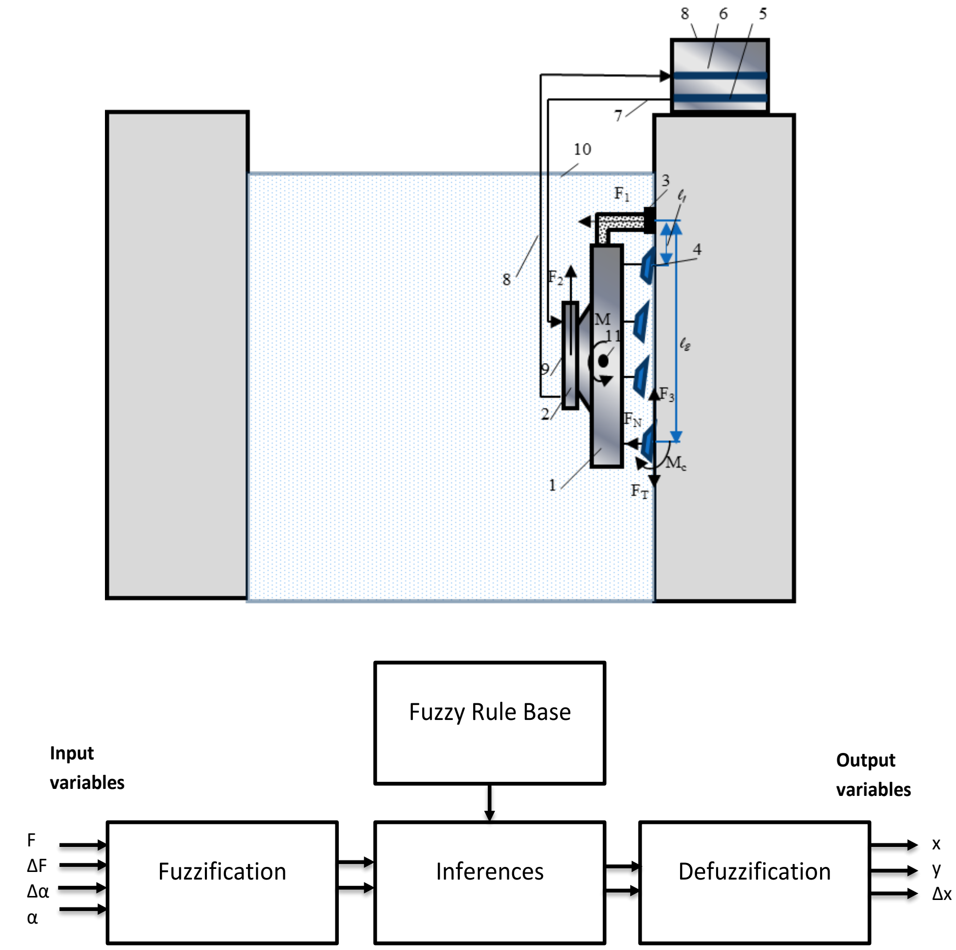


Fig. 19 Decision making and strategy of underwater wall climbing robot.

Multi – agent system.

UVS may be used as agent in multi-agent systems that forms wireless communication (Fig. 20).

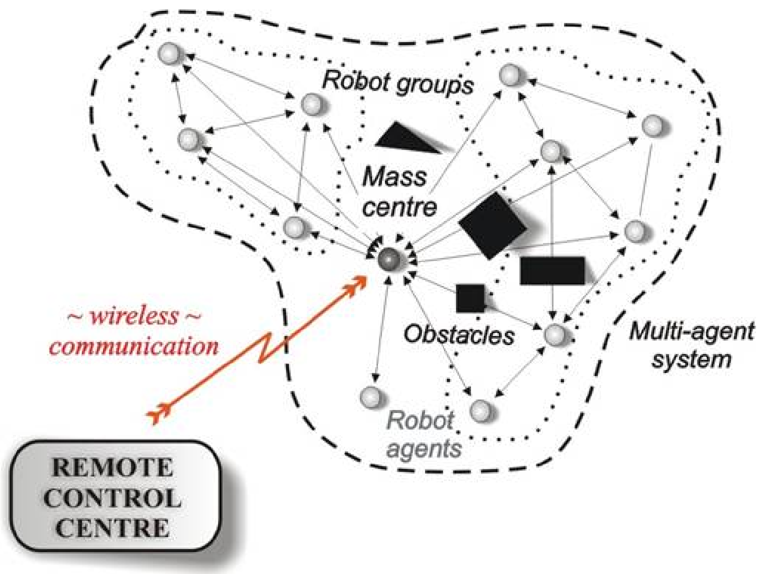


Fig. 20Multi-agent systems.

Robot agents are communicated between in undetermined environments with obstacles to solve predicted tasks. Another example is multi agent robot retro transmitter system, when command data may transmitted by parallel – sequences means.

UVS Software Challenges (Fig. 21) permit to satisfy connections between ground station – use GPS – airborne communication to find unmanned systems.

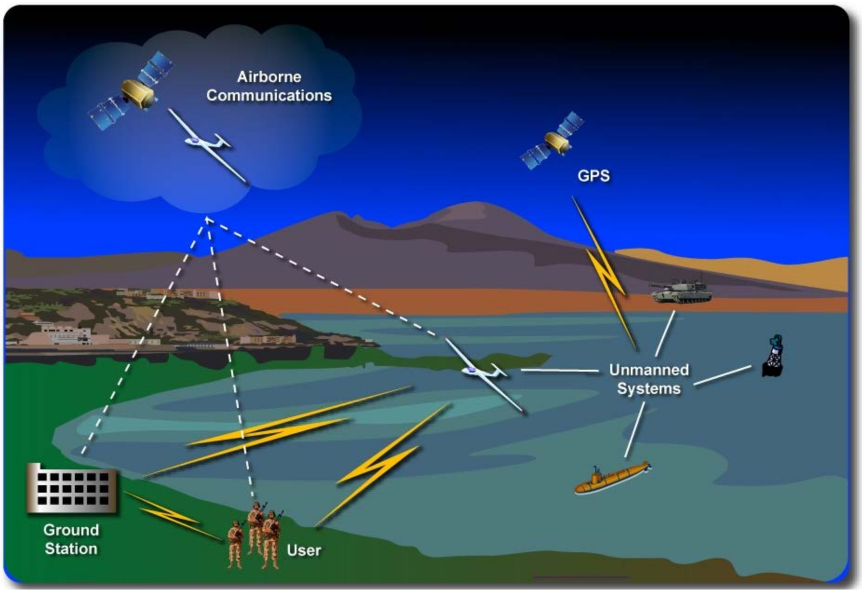


Fig. 21 UGV Software Challenges.

Fig. 22Control system for future artificial intelligence unmanned robot.

The problem of artificial intelligence creation in robotics.

Intellectual robots creation is one of important tendency in robotics. This is prolongation of UVS development in the part of thinking capabilities increasing of robots like human inteligence. Intelligent robot and artificial robot intelligence are the first next steps in the technical realization of human intelligence produced by human brain [24]. Physiological and psychologic features of human mind, its verbal and imagery components – the basis of intelligent and creative abilities. Verbal (symbols) mind of left semisphere of human brain based on formalized knowledge and creative abilities of right semisphere of human brain based on pattern minds (pattern recognition).

Control system includes two information channels – verbal intellectual control channel and pattern information control channel and it intended for design artificial intelligent robot of future as analogy of human brain.

Block module scheme of one version for future possible design for artificial intelligence robot is presented in Fig. 22. Every module includes local neuronnetworks, forming necessary information for control intelligence algorithms.

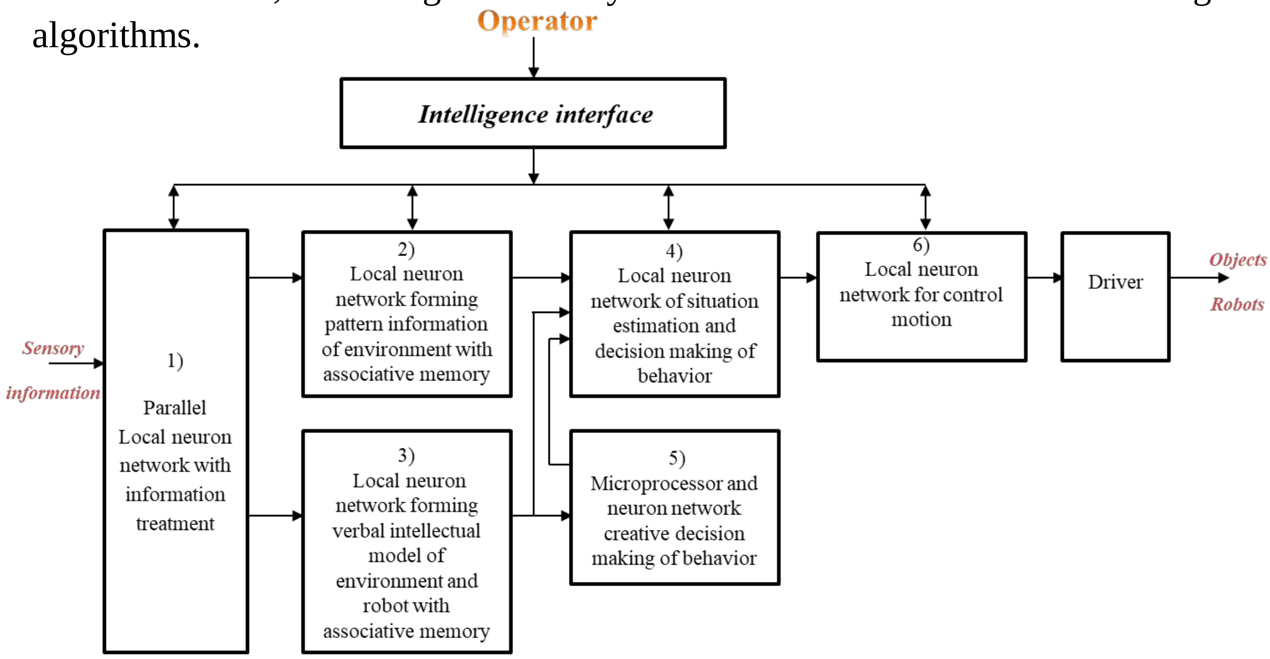


Fig. 22Control system for future artificial intelligence unmanned robot.

Neuron networks may be various type: cognitron or neocognitron types (modul 1), dynamic neurological and neuromorfological (modul 2), multymodules (modul 3), dynamic neurological (modul 4), genetic and evolution algorithms (modul 5), piramidal (6). Interaction between modules is shown in Fig. 22.

Smart City and UVS

“Smart City” is look in the future conception of information and communication technologies, including transport, for city estate and materials control. This intended for improve significantly human life, increase service quality and decrease resources.

Prof. McKinsey considers that up to 2020 years will be about 600 smart cities in the world, among those Tiandsin (cooperation China and Singapore, Masdar (UAE), and others.

“Smart City” is characterised by Smart Government, Smart Transportation, Smart Water, Smart Energy, Smart Buildings.

Smart transportation includes intelligence transport and logistic systems, trafic monitoring and contrl, fast reaction on extreme situations, intellectual parking, design of intellectual networks for logistic (Fig. 23).

Fig. 23 Smart Transportation in Smart City.

UVS public transportation is one of basic idea of smart city and smart transportation. All possibilities of UVS will apply in smart cities of the future. Many problems related with improving characteristics of new existing UVS will be solved in the future to adequate demands of Smart City traffic. Such behaviour of UVS like reliability, manoeuvrability, security, fast reaction on situation changing and so on have to be solved for future smart city transportation.

Acknowledgments.

This study w.as supported by the Program №.29 "Advanced Topics of Robotic Systems" (AAAA-A17-117121120021-9) of the Presidium of the Russian Academy of Sciences.

Conclusion.

Brief Review was presented to show UAS and UGV application and development. One of important goal of such kind of systems is the improvement of people life in all over the world. Especially when extreme conditions, undetermined environment, rugged terrain, dangerous conditions are existing.

Look in the future is discussed on more reliable fully autonomous smart system.

References

1. Zadeh L.A. Outline of a New Approach to the Analysis of Complex System and Decision Processes. IEEE Trans. SMC-3, NI, 1973, pp.28-44.

2. Sujeno M., Murofushi T., Mori T., Tatematsu T., Tanaka J. Fuzzy Algorithmic Control of a Model Car by Oral Instruction. Fuzzy Sets and Systems, 32, 1989, pp. 207-219.

3. Lee C.C. Fuzzy Logic in Control Systems: Fuzzy Logic Controller, Part 1 and Part II, IEEE Trans. on SMC, vol. 20, N2, 1990, pp.404-435.

4. Gradetsky V., Veshnikov V., Ulianov S. “Mechatronics Structure of Wall Climbing Autonomous Vehicle”, Proceed. of the ICAR’95 International Conference, Finland, 1995, pp. 150-155.

5. Pagni A., Poluzzi R., Rizzotto G. “WARP: Weight Associative Rule Processor. An Innovative Fuzzy Logic Controller”.IIZUKA’92 International Conference on Fuzzy Logic and Neural Networks.

6. Pagni A., Poluzzi R., Rizzotto G., Matteo Lo Presti “Automatic Synthesis, Analysis and Implementation of a Fuzzy Controller”, Proceed. of IEEE.

7. Weight Associative Rule Processor WARP 1.1 SGS-Thompson Microelectronics Group of Companies, Italy, 1994, p. 1-16.

8. Gyula Mester, “Intelligent Mobile Robot Motion Control in Unstructured Environments”, Acta Polytechnica Hungarica, Vol. 7, No. 4, 2010, pp.153-162.

9. Gyula Mester, “Obstacle – Slope Avoidance and Velocity Control of Wheeled Mobile Robots using Fuzzy Reasoning”, Proceedings of the IEEE 13th International Conference on Intelligent Engineering Systems, INES 2009, Barbados, pp. 245-249, ISBN: 978-1-4244-4113-6, Library of Congress: 2009901330, DOI: 10.1109/INES.2009.4924770, 2009.

10. Homayoun Seraji, Ayanna Howard, Edward Tunstel, “Terrain-based Navigation of Planetary Rovers: A Fuzzy Logic Approach”, Proceedings of the 6th International Symposium on Artificial Intelligence and Robotics & Automation in Space: i-SAIRAS 2001, pp. 1-6, Quebec, Canada, 2001.

11. H. Maaref, C. Barret, “Sensor-based Navigation of a Mobile Robot in an Indoor Environment”, Robotics and Autonomous Systems, Vol.38, pp.1-18, 2002.

12. W.L. Xu, S.K. Tso, Y.H. Fung: “Fuzzy Reactive Contrl of a Mobile Robot Incorporating a Real/Virual Target Switching Strategy”, Robotics and Autonomous Systems, Vol. 23, pp. 171-186, 1998.

13. Krzystof Kozlowski, Wojciech Kowalczik, “Motion Control for Formation of Mobile Robots in Environment with Obstacles”, Studies in Computational Intelligence, Towards Intelligent Engineering and Information Technology, Volume 243/2009, pp.203-219, ISBN 978-1-642-03736-8, Library of Congress: 2009933683, DOI: 10.1007/978-3-642-03737-5_15, Springer, 2009.

14. Gyula Mester, “Intelligent Mobile Robot Controller Desing”, Proceedings of the Intelligent Engineering System”, INES 2006, pp. 282-286, London, United Kingdom, 2006.

15. Gyula Mester, “Motion Control of Wheeled Mobile Robots”. Proceedings of the IEEE SISY 2006, pp. 119-130, Subotica, Serbia, 2006.

16. Gyula Mester, “Improving the Mobile Robot Control in Unknown Environments”, Proceedings of the YUINFO’2007, pp. 1-5, Kopaonik, Serbia, 2007.

17. Gyula Mester, “Obstacle Avoidance of Mobile Robots in Unknown Environments”. Proceedings of the IEEE SISY 2007, pp. 123-128, Subotica, Serbia, 2007.

18. Gyula Mester, “Obstacle and Slope Avoidance of Mobile Robots in Unknown Environments”. Proceedings of the XXV.Science in Practice, pp. 27-33, Schweinfurt, 2007, Germany.

19. Gyula Mester, “Obstacle Avoidance and Velocity Control of Mobile Robots”, 6th International Symposium on Intelligent Systems and Informatics, Proceedings of the IEEE SISY 2008, pp. 1-5, IEEE Catalog.

20. Tamas Szepe, “Sensor-based Control of an Autonomous Wheeled Mobile Robot”, Proceedings from PROSENSE 3rd Seminar Presentations, pp. 34-37, Institute Jozef Stefan, Ljubljana, Slovenia, January 2010.

21. Tamas Szepe, “Robotiranyitas tamogatasa tavoli erzekelorendszerrel”, VMTT konferencia, konferenciakiadvany, pp. 527-532, Ujvidek, Szerbia, 2010.

22. Pozna, C., Prahoveanu, V., Precup, R-E., "A New Pattern of Knowledge Based on Experimenting the Causal Relation", Proceedings of the 14th IEEE International Conference on Intelligent Engineering Systems INES 2010, pp. 61-66, Las Palmas of Gran Canaria, Spain, 2010.

23. Pozna, C., Precup, R-E., Minculete, N., Antonia, C., "Properties of Classes, Subclasses and Objects in an Abstraction Model", In Proceedings of the 19th International Workshop on Robotics in Alpe-Adria-Danube Region, RAAD, 23-25 June, 2010, pp. 291-296, Budapest, Hungary, 2010.

24. E. Iyrevich, L. Stankevich "Prospectives of Creating Artificial Intelligence in Robotics", Machinary, Bulletin of Moscow State Technical Bauman University, Special Issue Robotics and Mechatronics, 2011, pp. 13-16.