# Safety, Uncertainty, and Real-Time Problems in Developing Autonomous Robots

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*Abstract:* - Recent developments in robotics outside traditional industrial applications increasingly focus on operation of robots in an unstructured environment and human vs. robot interactions. Examples of new applications of robots in unstructured environments that are actively pursued today are personal and service robotics, space and underwater robotics, medical and rehabilitation robotics, construction robotics, and agriculture robotics. The new trends in robotics research have a general goal of getting robots closer to human social needs. In this case a key problem of robotics is the problem of safety of robot and its surrounding. For safe autonomous functioning in a dynamic unstructured environment, a robot should possess a capability of real-time data processing under information uncertainty. These three issues - safety, uncertainty, and real-time data processing are closely related: planning safe actions based on uncertain data usually requires more computation than planning without uncertainty because multiple possible outcomes of actions should be considered. The main sources of the uncertainty are inaccuracy of sensorial data measurement, time-delay of sensorial data acquisition and processing, and time-delayed feedback in a robot's control system. As increase of accuracy of measurements and speed of data processing has technical and economic restrictions, there is a necessity for search of practical decisions in the conditions of existing possibilities. We propose a method of real-time data processing under information uncertainty that deals collaborative processing of various data, visual and non-visual. Finally we present the examples of application of the proposed method for building of robot's environment model and for robot motion planning with obstacles avoiding.

*Key-Words:* - Service robotics, Robot architecture, Global optimization, Robot world infrastructure.

## 1 Introduction

The new trends in robotics research focus more on the autonomous and semiautonomous robots oriented to action in unstructured environments. Some researchers relate such robots to a class of service robots.[1] According to the International Federation of Robotics service robot is a robot that operates semiautonomously or fully autonomously for performing services useful to the well being of humans and equipment, excluding manufacturing operations. Depending on their functions and applications service robots are divided into professional service robots and personal service robots. Professional Service Robots are used in a variety of applications at work, in public, in hazardous environments, in locations such as deep-sea, battlefields and space, just to name a few. In addition to the service areas such as cleaning, surveillance, inspection and maintenance, we utilize these robots where manual task execution is dangerous, impossible or unacceptable. According to such classification space and underwater robots, medical robots, robots for application in agriculture and construction, and green and sustainable robots relate to professional robots. Personal robots are service robots that educate, assist, or entertain at home. These include domestic robots that may perform daily chores, assistive robots for people with disabilities or elder people, and robots that can serve as companions or pets for entertainment.

Professional Service Robots are more expensive than personal (domestic) robots. According to the United Nations Economic Commission for Europe (UNECE), there are over 20,000 professional service robots in use today valued at an estimated US$2.4 billion. If personal entertainment robots and domestic robots such as vacuum cleaners, floor cleaner, pool cleaner, gutter cleaner, and robotic toys are included, this number is well over US$3.5 billion. The common feature of such robots is that they are some specialized systems of single-function appliances. They perform their functions well and at a reasonable price but their relation to robots defined as multifunctional system is explained rather by commercial reason.

To assist the human and "to live" among people, the personal service robot has to be a multifunctional system and should possess certain level of intelligence. Robots have to be able to communicate with a user and other technical systems including other robots, to process and interpret sensors data, to synthesize the environment model and to monitor the environment state, to plan goal-directed activity, and to realize the plan. It is obvious that these requirements correspond to the general requirements to Intellectual Robotics.

To bring near the time of creation and practical use of multipurpose service robots it is offered to combine two approaches to the problem decision. The first is to increase robot intelligent abilities using in same time specific abilities of the robot which are distinct from abilities of the human beings. The second is to adapt an inhabitancy of the human beings to requirements and possibilities of robots, simplifying thereby the solution of the difficult scientific and technological problems related to maintenance goal directed robot behavior in unstructured dynamic environment. In other words, it will be productive to create a parallel robot world and adjust it with human being world giving particular attention to safety of the robot actions for the external world and robot. The concept "safe state" is defined as a state at which there is no unforeseen mechanical contact between the robot and objects of its environment and there are no factors causing infringement of a regular (working) condition of the robot (balance loss, excess of admissible back forces, etc.). The current state of the robot in significant measure is defined by the accuracy of internal and external sensor systems and by the time of sensor data processing. The limited accuracy of the sensor data and essential delays of time between measurement and getting results of data processing have led to necessity of developing algorithms of control that take account the data uncertainty. We'll discuss some heuristics that allows us to take account the uncertainty and to reduce the time of safe path planning during the analysis of robot architecture and subsystems of sensor data processing and robot motion planning.

The different nature of human beings and technical systems defines a basic difference between them: the universality of the first one and the specialized domain of functioning of the second one. As a universal system the human being needs to solve a variety of problems of different nature. It is problematic to reproduce the universality of human being, but when creating applied autonomous robots predestinated for functioning in a limited problem domain we do not need to design them as universal systems. It is not an artificial restriction: the activity domains differentiation and specialization is widely used by the human being (e. g., workers constructing roads and workers constructing automobiles represents the groups of different specialization).

In designing applied autonomous robots we can follow the general principles of the human functioning and behavior such as the cooperative human being subsystems functioning (sensory-motor functions), cooperative functioning of the human community, creating special infrastructures and information support to simplify a human community functioning, and the activity domains differentiation and specialization. At the same time, it is possible to use the fact that technical systems and human beings can execute some similar actions in a different way. Some times technical systems can perform better than human beings. For example, the autonomous robot can be equipped with a set of sensors that allowed it to perceive signals that can't be perceived by the human beings, can provide the simultaneous omnidirectional vision, can measure the distance with high accuracy, and for a long time can record exact positions of the objects of its surrounding. This approach was followed to design the information support for autonomous robot functioning.

The paper is structured as follows: Section 2 describes our approach to development of an architecture of autonomous robots that provides robot subsystems cooperative functioning. In Section 3 we present the arguments for selection of the algorithms used by the subsystems of proposed architecture and describe some heuristics directed to reach the real time mode of functioning some algorithms of global optimization in respect to their specific domains. Section 4 introduces our approach to artificial landmarks application to simplify a problem of robot autonomous functioning and to close upon the rules of safety of both human being and robot communities. In Section 5 we describe some examples of practice application of developed means to modeling professional and personal robotic systems. Finally, some conclusions and future work are pointed out.

## 2 Distributed autonomous robots architecture centralized by knowledge

Before the description of the proposed architecture let us compare the approaches to autonomous robots architecture generalized in [2] – [4]. Fig. 1 illustrates the three-level architecture from N. Nilsson [2], fig.

25.4. Without detailed analysis of the presented architecture it is possible to note that it exploit a unidirectional data stream starting with the sensors signals and terminating at motors commands. This approach presents the independent data processing by the sensor subsystem and by the subsystem of acts planning and realizing. It does not presuppose a direct interaction between different towers. The same conclusion can be reached regarding the architectures generalized in [3] and [4].

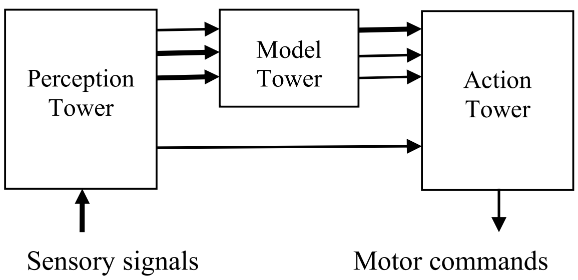


Fig. 1 Tower

The feedback carried out through an environment and sometimes used as an argument of existing bidirectional communications between the executive subsystem and the sensorial subsystem is not the same as direct data exchange between subsystems about the transformations in the robot environment provoked by its actions or about the new robot state. The offered architecture differs from architectures mentioned above by the bidirectional communications that provides a direct interaction between corresponding subsystems.

The approach, based on the cooperation of various subsystems that provides the robot autonomous functioning, was proposed in [5]. Using the terminology of [3] and [4] the corresponding architecture can be named as Distributed Autonomous Robots Architecture Centralized by Knowledge. Cooperative functioning of the robot subsystems is defined as the work of all participants to reach the general goal defined by the user and to reach a special common goal that provides or assists successful functioning of each of them. The Distributed Architecture Centralized by Knowledge provides cooperation of all subsystems, such as user-robot dialog supporting, sensor data analysis and world and robot state verification, safe trajectory self planning, and movement control (Fig.2).

"Centralized by Knowledge" means that the knowledge of the current spatial state of the robot and its environment is defined as a special common goal for all robot subsystems: Each of subsystems sends the corresponding information discovered to the subsystem of the monitoring robot and environment state and has access to the information accumulated by this subsystem to use it for solving its particular problems. "Robot and environment state" is interpreted as the position and orientation of robot and objects of its environment. It is clear that the state of the robot and its environment is defined in the result of processing the information of internal and external sensors of the robot.

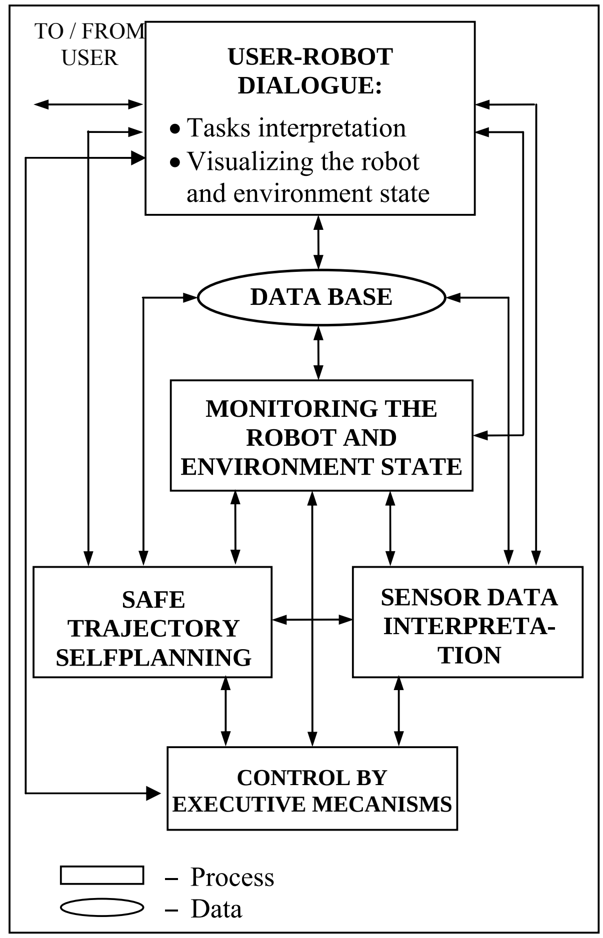


Fig.2 Autonomous Robot Distributed Architecture Centralized by Knowledge

"Distributed" means that all subsystems have autonomy and can cooperate with each other in solving their particular problems. All subsystems work in parallel, every one in its specific domain. Every subsystem uses the individual presentation of the model of the environment and the robot model adapted to the process destination. It provides some liberty in the solution of problem of world representation. The information common to all subsystem is: the name of the object model and its spatial state (the position and orientation of the coordinate system of object model with regard to the world model coordinate system. The object name and the object model coordinate system are common for all subsystems.

The knowledge of a current spatial state of the robot and its environment enables us to interpret the model of robot environment as a closed one in the meaning of the material and information flows, which is an indispensable condition of the robot autonomous functioning. It does not mean that robot environment is unchangeable. It means that the possible change can be discovered by the subsystem of sensor data analysis and world and robot state verification.

At the same time, the knowledge of a current spatial state of the robot and its environment can simplify the solution of the particular subsystem tasks. For example, for the subsystem of sensor data interpretation a difficult problem of 3D scene recognition can be reduced to the problem of its expected state verification. In this case it is necessary to define the correspondence of the grasped image of an object to the sample of an object of known class in known position. The problem of pattern recognition appears only in the case of negative answer, but in the same time positive answers for other objects significantly reduce the unspecified space and the number of unknown objects classes of an unspecified part of the image.

## 2.2 Architecture implementation

The proposed architecture is implemented using as a kernel the mobile robot PowerBot equipped with a set of the sensory systems (ActivMedia Robotics, U.S.A.) [6], predestined to investigations in the field of the Intelligent Robotics. It includes the arm of 6 degrees of freedom that is the Industrial Robot PowerCube (Amtec GMB, Germany) [7] (Fig.3, 4). ]

Fig.3 Mobile Robot PowerBot with Industrial Robot PowerCube

The PowerBot contains a mobile platform of two-wheel differential with balancing casters. Each drive shaft is equipped with a high-resolution optical quadrature shaft encoder for precise position,

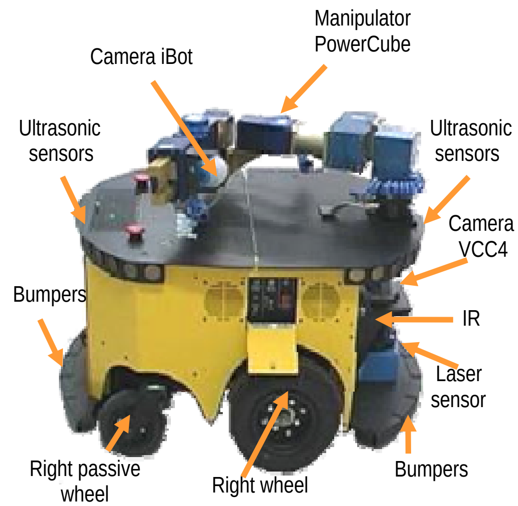


Fig.4 Mobile Robot PowerBot components

direction, and speed sensing, and advanced dead-reckoning. The PowerBot contains the basic components for sensing and navigation in a real-world environment. It is equipped with an onboard, internally–integrated, industrial–grade PC, four sonar arrays, 2 x 14 sonar front and rear, sensing up to six meters; a single plane range-finding sensor of 180 – 360 readings in 180 degrees; four infrared step sensors, in pairs on each side of robot; the PTZ color camera accessory with framegrabber.

The Industrial Robot PowerCube is the manipulator of 6 degrees of configuration RPRPPR (P – pívot, R - rotation) and is equipped by the analog camera iBot. The producer's software realizes only the manual control and does not provide the manipulator functioning in the autonomous mode. Basic means (algorithms and software) related to robot autonomous functioning developed at the Robotics Laboratory at U.T.M. allows us to overcome this limitation.

An enhancement of the PowerBot computational base is fulfilled by creating a local network containing the onboard PC and 4 additional portable computers, that allows us to adapt the PowerBot to the Distributed Architecture Centralized by Knowledge [8]. To realize this cooperation of different subsystems or of different sensor data processing procedures of the same subsystem it is necessary to establish the time-correspondence between data of cooperating sensors. It relates to both

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the synchronous and asynchronous multisensor systems due to the parallel manner of measurement for the sensors of different types with different time of the data processing. It is done by adding to the mentioned above local network the node that includes the timer that is used to form the labels which correspond to the instants of sensor measuring with respect to a single count time beginning. The timer is implemented in hardware [9]. The example of sensor data labeled with the instants more closed to the instant of measuring with the laser sensor are presented in the table 1.

### 2.3 Subsystems of the Distributed Autonomous Robots Architecture Centralized by Knowledge.

**Subsystem of user-robot dialog** assumes the task formulation can be given in a human-like language [10]. The task formulation in a standard documentation of mechanical assembling was analyzed. The analysis of the vocabulary content and of the typical phrases used in the documentation indicates the opportunity to create the dialog system without vocabulary shortage (the vocabulary appeared limited enough). The task formulation in a human-like language is transformed into macro operators of the task oriented language [11]. The specification of technological assembling rules (the type of connection, torque, etc.) corresponds to documentation of mechanical assembling and is used for specification of robot operations from the data base. The interpreter of operators of task oriented language formulates the tasks for the subsystem of safe trajectory self planning and the tasks for the subsystem of sensors data interpretation.

The subsystem of user-robot dialog visualizes the trajectory planned by the subsystem of safe trajectory self-planning in the form of video. Color mono images of orthogonal and central projections and stereoscopic images are generated for model visualization. The user can correct the trajectory planned. It is possible to select in the generated video the part of trajectory for correction by marking its initial and terminal frames and inserting with a 3-D marker the intermediate points that must be passed. The geometrical model of three-dimensional objects exploited by the subsystem of user-robot dialog for visualizing the robot and its environment state are represented by sets of convex polyhedrons and such primitives as sphere and cylinder.

**Subsystem of safe trajectory self-planning** allows us to plan a path of goal directed movement with obstacle avoidance [12]. The safe path planning is done in the robot configuration space. The task is formulated as a safe path search on the graph of corresponding dimensionality. The algorithm is based on the algorithm A* intended for off-line programming application. The graph is presented in an implicit form and is constructed during the path searching. The definition of the occupied nodes of the part of graph that are under construction is carried out during the search by computing the minimum distance between the robot and obstacles. In the case of manipulator path planning to define the spatial position of each part of manipulator modeled the direct cinematic task is solved for each investigated node of graph.

**Table 1**

| Measured parameters | Data | Time [ms] |
|---|---|---|
| Translation distance [ticks] | | |
| Left wheel | 843247 | 54896.8186 |
| Right wheel | 843240 | |
| *110ticks=1mm | | |
| Translation velocity of robot [mm/s] | 505.0000 | 55737.3828 |
| Rotational velocity [°/s] | 0.0000 | 55737.3828 |
| Translation velocity [mm/s] | | |
| Left wheel | 505.0000 | 55737.3828 |
| Right wheel | 505.0000 | |
| Distance [mm] | 2305 | 54906.1155 |
| Sonar number | 2 | |
| Distance [mm] | 807 | 54902.0122 |
| Laser angle [°] | 90.0 | |
| Image | | 54880.1910 |

The result of safe path search is the sequence of points in the space of states of the robot executive mechanisms. The sequence of points of each degree of freedom with the given accuracy is approximated by a broken line by the algorithm of iterative selection of terminal points.

Geometrical model of the robot and of objects of its environment exploited by the subsystem of safe trajectory self-planning is presented by a set of the convex polyhedrons with minimum number of the vertices.

**Subsystem of sensors data interpretation** is used for the scene recognition and for verification of the spatial state of the robot and its environment. Main feature of this subsystem, based on the subsystems cooperative functioning, is the possibility to substitute the problem of verification of the known scene current state for the problem of scene recognition.

Initial data: The images of TV-mono-cameras and images of the stereo system, distances measured with laser and sonar sensors data. The stereovision algorithms are based on the processing of the images of stereo pair and on the recognition of the marks with known three dimensional positions in the coordinate system of the object model.

Model of the three-dimensional object: A set of the structural elements (the flat and curved surfaces of the second order of curvature) and spatial relations between them.

Method of recognition: The method of the stochastic labeling ([13], [14]) proposed by Faugers et all ([15], [16]). Principal characteristic of the methods of the three-dimensional objects recognition is use of combined processing the visual data and the data of spatial measurement [17].

**Subsystem of current state monitoring** represents the model of the three-dimensional object by the name of the object model and its spatial state (the position and orientation of the system of coordinates of the object model with regard to the world model coordinate system). The principal characteristic of this subsystem is that it registers the information from subsystems only if it differs from the memorized information and sends to subsystems only the information about the changes of the current state of the environment and of the robot.

**Subsystem of control by executive mechanisms** transforms the path planned by the subsystem of safe path self-planning, represented as the broken line, to a trajectory, i.e., to a function of time, approximating the broken line by the sequence of linear segments with parabolic links.

## 3 Arguments for the subsystems algorithms selection

General principle of developing the algorithms of subsystems functioning is formulated as follows. The algorithms have to be ones of global optimization in respect to their specific domains and it has to be anticipated auspicious conditions of algorithms implementation in hardware and with parallel calculations.

### 3. 1 Stereovision algorithms

Stereo vision is an important cue for visually guided robots. It can be used for objects shapes and pose recognition in the task of visually guided manipulation and for scene description for visual navigation and obstacles detection. A binocular stereo system consists of two different cameras separated by a fixed baseline. The cameras can be located in parallel (passive stereovision) or can form an active stereovision system with dynamic vergence [18]. Reconstruction of 3D scenes from stereo pairs is based on matching of corresponding points in the left and right images. We call corresponding those points which represent one and the same surface elements on each of the stereo pair images. The distance to the scene points visible on the left and right stereo-images are unambiguously determined by the relative displacement (disparity, parallax) of identical points on the images. The disparities (parallaxes) of corresponding points are defined as the differences of these points' coordinates in a conventional coordinate grid attached to both images. In particular, the epipolar constraint reduces a 2D search space to 1D search along epipolar lines. For each point observed in one image the same point must be observed in the other image on on the associated epipolar line. The epipolar lines corresponds to the lines of intersection of each camera's image plane by the epipolar plane passed over the analyzed scene point P and the focal points of the left and of the right cameras. The epipolar geometry is simplified if the two camera image planes coincide. In this case, the epipolar lines also coincide. Furthermore, the epipolar lines are parallel to the line between the focal points and can in practice be aligned with the horizontal axes of the two images. This means that for each point in one image, its corresponding point in the other image can be found by looking only along a horizontal line. To determine distance to an object in real-time mode stereo vision systems use triangulation based on epipolar geometry with horizontal epipolar lines.

To solve the problem of automatic identification of corresponding points on stereo pair images, it is necessary to take into account those image distortions which arise in the stereo measuring process. The visual effect of the changeable form of 3D surface processed (relief) is expressed not only in the displacements of corresponding points used for distance calculation but also in the simultaneous change of scales (i.e., extension or compression) of one identical region that contains the corresponding point with respect to another. The magnitude of such geometric deformations is different for different regions and is determined by the particular characteristics of the relief and the stereo measuring conditions (distance to surface measured and distance between focal centers of two cameras (base of stereo system). In addition to such "regular" distortions, one may observe various random deviations of identical regions, caused by no uniformity of the reflecting properties of scene surfaces in different directions, by the noise in signal channels, etc. The uncertainty in distance definition, complexity of the algorithm realization and time of calculations is defined by the measure in what the stereo matching algorithm considers influence of the mentioned and other factors.

The majority of known algorithms of stereovision used in robotics belongs to the algorithms based on searching maximum of cross-correlation between small image picked out by small window from one stereo-pare image and a sequence of images of the same size picked out along the associated epipolar line of another image. This technique is widely used in practice due to the possibility of real-time realization. In the same time, the violation of many constraints leads to accumulation of errors due to local decision making and is the reason to use the algorithms based on global optimization.

In a difference of local patches comparison used by the most of known algorithms the dynamic programming algorithm makes decision based on the data processing of the whole epipolar line that provides more reliable results realizing the technique of global optimization This technique firstly was introduced by G.L. Gimelfarb, V.B. Marchenko, V.I. Rybak, , 1972 [19], 1976 [20]. In common words, dynamic programming allows us to realize in practice the stereo matching by the method of analysis via synthesis. It means that it is possible to synthesize different images that correspond to permissible. Then the problem of finding the optimal permissible transformation reduces to the equivalent problem of searching for the path of maximum length on such a graph transformations along, for example, left epipolar line to match them to the image of right one. These algorithms the same as the local algorithms mentioned above belongs to so called algorithms of the asymmetric optimization. Asymmetric means that, in common case, the results of matching the left image as a sample with the right one does not coincides with the results of matching the right image as a sample with the left one.

Gimelfarb in 1979 [21] introduced symmetric dynamic programming algorithm that forms the theoretical base for development of advanced algorithms of stereovision by many researchers. The symmetric algorithm directly uses as the sample the visible parts of scene, more precisely, the spatial coordinates and photometric characteristics of visible points. The aim of data processing is to find a sample that minimizes the maximum distance from the sample to each of stereo images.

In 1981 Baker and Binford [22] proposed an dynamic programming stereo matching based on searching corresponding edges of the images of an stereo pair. It means that as initial data they used the data received after special image preprocessing, no original image intensities, so, the final result depends on accuracy of preprocessing.

A stereovision algorithm based on searching correspondent points defined as centroids of some special marks proposed by V. I. Rybak, V. M. Krot, A. V. Khomenok, 1992 [23] does not require the dynamic programming technique application. It exploits the recognition of corresponding marks in the left and right images of stereo pair. This algorithm was developed for a precise measuring of the mutual spatial states of mechanical parts during robot assembling.

The algorithm of stereovision used by subsystem of sensors data interpretation developed by V.M. Krot, [24] is related to the class of symmetric dynamic programming algorithms of stereovision. The important characteristic of the algorithm developed in [24] is the estimation of reliability (confidence) of results obtained based on the statistical criterion that can be used by the algorithms of 3-D objects recognition with uncertainty

The algorithms based on dynamic programming technique allow us to implement them in hardware. Graph hardware implementation is a practical way to reach stereo search in a real-time mode. One of possible hardware implementation of DP graph was proposed by V. Rybak, in application to solving the problem of hand written letters recognition during writing 1972 [25]. A hardware implementation of the Viterbi algorithm in case of binary signals using FPGA technology is proposed by Hema.S, Suresh Babu.V, Ramesh P., [26] 2007 (The Viterbi algorithm is a DP algorithm for finding the most likely sequence of hidden states – called the Viterbi path – that results in a sequence of observed events, especially in the context of hidden Markov models, conceived by A. Viterbi in [27], 1967.

It is necessary to mention that for all types of stereovision algorithm meet with a problem when a scene contain isolated objects that provoke the "jump" of disparity more than the depth that is permissible for algorithm. As one of the option for problem solution we use cooperation of stereovision with laser sensor data processing to select the continuous areas and to estimate the distance to them.

### 3.2 Safe motion planning

The subsystem of safe trajectory self-planning use the algorithm A* that belongs to a class of global optimization algorithms. Till now the application of the algorithm A* to a safe path searching corresponds to a general line that is to give preference to the global optimization methods. In 1994 Stentz [28]. introduces a new algorithm, D*, capable of planning paths in unknown, partially known, and changing environments in an optimal manner. In 1995 Stentz proposed the generalization of A* to dynamic environments as the Focussed D* algorithm for real-time replanning, [29].

As was shown by Gonzales and Stentz [30], 2005 their planner used for mobile robot navigation in outdoor environments without GPS with planning with uncertainty is a modified version of A*. They also showed [31] 2005 that in the case of solving the problem of safe path planning with uncertainty in position sing high-resolution maps the methods based on solving a Partially Observable Markov Decision Process are not as efficient as deterministic search, especially A*.

The algorithm A* used to safe path planning allows the parallel calculation of the costs of the graph nodes that are the neighbors of the analyzed node (up to728 in the case of 6D space). It is possible to calculate in parallel the minimum distance between each of the convex polyhedrons that represent the robot elements to polyhedron – obstacle.

The algorithm for finding minimum distances between robot and obstacles is based on the optimization of the positions of the support planes of two convex polyhedrons [12]. The algorithm differs from the GJK-algorithm: [32]. The search of the minimum distance is done by the iterative calculation according to max-min criterion that maximizes the minimum distance between parallel support planes of two convex polyhedrons.

The geometrical model of the robot and of objects of its environment exploited by the subsystem of safe trajectory self-planning is presented by a set of the convex polyhedrons with minimum number of the vertices. For example, to minimize the time of calculating the minimum distance between the manipulator and obstacles the geometric model of manipulator PUMA-560 elements is presented by the r-spherical extensions of two line segments and two planar three-vertex-polytopes with individual radiuses of extension for each element.

## 4 Simple multifunctional landmark

Artificial landmark-based navigation in unstructured environments is a topic of intensive investigation. There are different physical types of artificial landmarks used for terrestrial, underwater and aerial robots navigation. Artificial landmarks, adopted to distinguish by visual sensors, presented in self-similar patterns, invariant to scaling, rotation, and viewing angle can serve as artificial landmarks whose detection indicates the presence of a landmark. The notion of self-similar landmarks was first used in a robotic context by Scharstein and Briggs, 2000 [33]. Their objective was to develop planar targets that would be detected easily with a standard perspective camera on a mobile indoor robot. A.Negre, C. Pradalier M. Dunbabin 2007 [34] introduced robust vision-based target recognition by presenting a novel scale and rotationally invariant target design and recognition routine based on self-similar landmarks. This landmarks can be used to guide and autonomous underwater vehicles for homing and docking operations. E.Celaya, J-L Albarral, P. Jim´enez, C. Torras, 2007 [35] proposed to attach to the landmark second pattern composing a binary code that can serve as identifier. A.Negre, C. Pradalier and M. Dunbabin, *Robust Vision-based Underwater Target Identification & Homing Using Self-Similar Landmarks*. Author manuscript, published in 6th International Conference on Field And Service Robotics - FSR 2007, Chamonix - France, 2007 .

Mostly these types of landmarks serve to robot to define the directional information. To define robot location a set of landmarks is used.

We introduce the simple model of a multifunctional landmark that could be easily detected and identified and that allows the robot to define its position and orientation in 3D space with respect to the landmark coordinate system. It means that for known spatial state of the landmark with respect to a global coordinate system robot can define its global position and orientation. In the same time, if the spatial state of some object is defined with respect to the landmark coordinate system the robot can recalculate these data with respect to its own coordinate system that is important capability for service multifunctional robots

The landmark (fig. 5) is a planar target that can be detected easily with a mono camera on a manipulator or on a mobile indoor or outdoor robot. The camera has to be calibrated and the parameters of distortion compensation have to be known.

In the first experimental version, a landmark is composed of four circles (subtargets). (The selection of circles is not critical. As subtargets can be used different types of marks including self-similar landmarks.) The algorithm of image processing defines 3D coordinates of the centers of circles with respect to the camera coordinate system; restore the

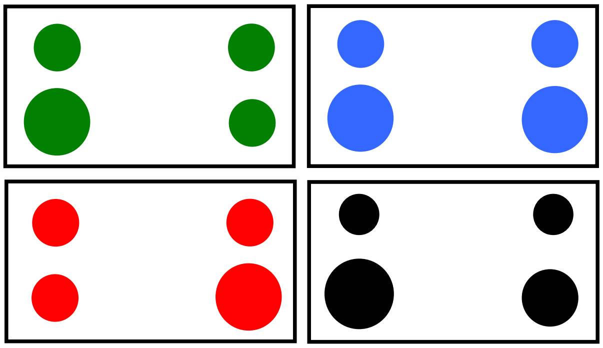

Fig. 5 Landmarks of different combinations of subtarget area relations of the corresponding subtargets and colors.

landmark coordinate system and calculates the parameters of the transformation matrix from the landmark coordinate system into the camera coordinate system and inverse one.

As a landmark identifier serve the combinations of circle area relations of the corresponding subtargets, the color of subtargets and background. To define the landmark orientation it is possible to design asymmetric subtarget positions.

Some examples of landmarks application are presented in Fig. 5 – 9.

Fig. 6 Mobile robot PowerBot equipped with landmarks.

Fig. 7 Indoor landmarks


Fig. 8 Landmark combined with guide


Fig. 9 Landmarks combined with traffic sign

Additional information associated with the landmark can be recorded in robot memory and used for goal directed actions planning. Combined with guide marks of a human being infrastructure this type of landmarks would serve for closing upon the rules of safety of both human being and robot communities.

The capability to relate the spatial parameters of the robot with respect to the landmark coordinate system allow us to combine topological and metric maps that can simplify the task of service autonomous robot navigation and docking at objective place.

Landmarks located at a robot board allows other technical systems including other robots identify and define spatial position and movement characteristics of the first one.

# 4 Examples of practical application of professional service robot

## 4.1 Information technologies for cleaning territory from radioactive materials.

(Contract of the International Center of Information Technologies and Systems of the Ukrainian Academy of Sciences with the Chernobyl Nuclear Power Plant, Ukraine)

This work was fulfilled by the Department of Informatics in Robotics of the International Center of Information Technologies and Systems of the Ukrainian Academy of Sciences . After successful development of the means for realizing the distributed architecture centralized by knowledge they were used to design the information technologies applicable to extraction by the remotely controlled robots of the radioactive materials from the under-reactor rooms of the Chernobyl Nuclear Power Plant block destroyed as a result of failure. The high level of radiation limits the life time of mechanisms used for cleaning territory from radioactive materials. Preliminary planning and simulating the actions of remotely controlled robots can provide a more effective their use.

The problem has been formulated as follows: Develop for the given family of remotely controlled robots the information technologies for preliminary planning of the robots actions of extracting from under-reactor rooms the radioactive materials and searching the solution in the case of complex unforeseen situation during their work. Initial data: the drafts of construction documentation of the under-reactor rooms in the state before the failure, the drafts of technical documentation of the remote control robots, and the data of stereo heads that can be inserted in the rooms.

The information technologies developed were destined to solve the next tasks.

Designing the TV-stereo-system software for computing the 3-D coordinates of the points of surfaces of the formations originated by the failure using the data of stereo heads inserted in the rooms;

Designing the 3-D geometric models of the under-reactor rooms in the state before and after the failure using the drafts of construction documentation and the data of stereo-measuring ((an example of the models visualized in fig. 10, fig. 11);

Designing the cinematic and 3-D geometric model of remotely controlled robots (geometric models of two robots are presented in fig . 12 – the same vehicles can be equipped with various instruments);

Preliminary planning of the safe path of robot movement (location where robot tilt deviation is out of range permissible is also interpreted as an obstacle);

Searching the solution in the case of an unforeseen situation with a simulation based on the robot safe path self-programming;

Visualizing the scene model that corresponds to given TV-camera position and orientation.

The form of planned safe path presentation is shown in fig. 13. The path is marked by triangles on the plan of room. The operator of the remotely controlled robot can match the correspondence of the real robot’s position to the path preliminary planned. This is done by comparing the image perceived with the real TV-camera mounted on the robot with the virtual image generate.

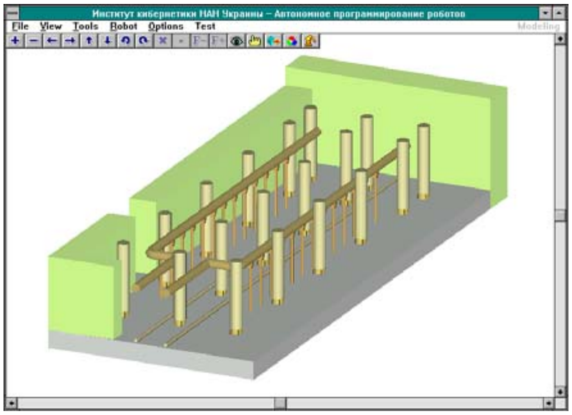


Fig. 10 Geometric models of the under-reactor room before the failure

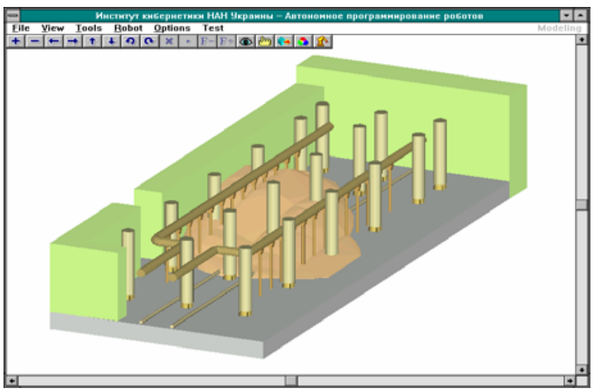


Fig. 11 Geometric models of the under-reactor room after the failure

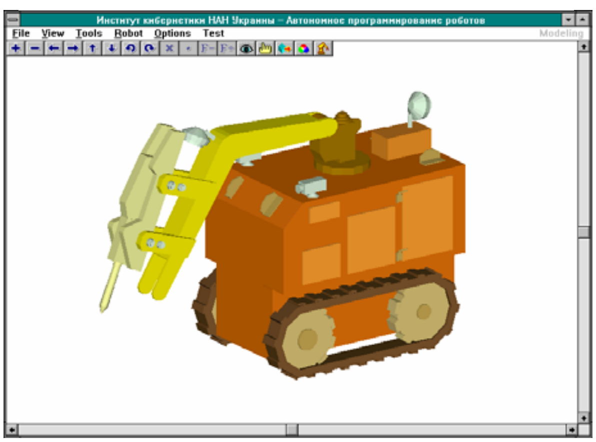


Fig. 12 geometric model of remotely controlled robot

The generated image presented in fig. 14 corresponds to the awaited image that can be perceived by the robot TV-camera if the robot is located at the given position of the preliminary plan (green mark in the fig. 13).

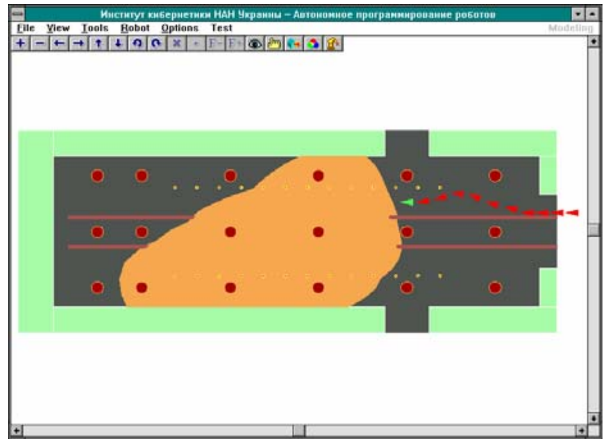


Fig. 13 The form of planned safe path presentation

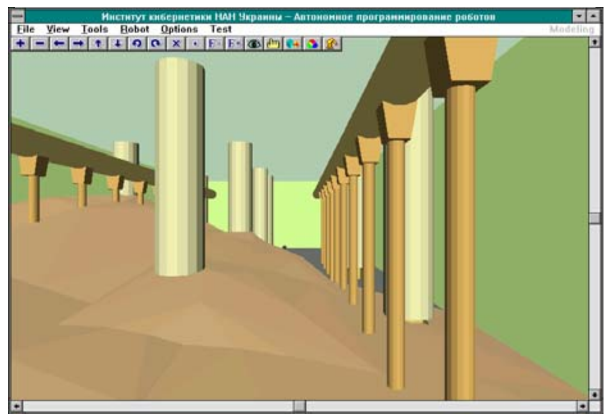


Fig. 14 Generated image presented that have to corresponds to the awaited image that can be perceived by the robot TV-camera

### 4.2 Simulation of human - robot cooperation while assembling stiffening girder on space orbit.

(Contract № 6-122/96 of the International Center of Information Technologies and Systems of the Ukrainian Academy of Sciences with the Ukrainian National Space Agency)

The means developed for realizing the distributed architecture centralized by knowledge were used for simulating the tasks of cooperative functioning astronaut and autonomous robot while assembling constructions on the orbit.

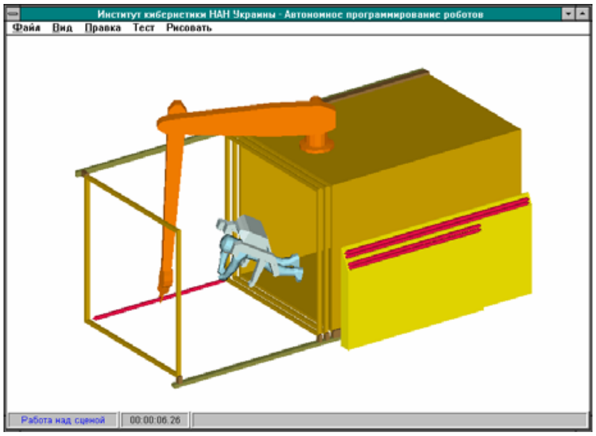

Fig. 11 The first operation of lock joint fulfillment

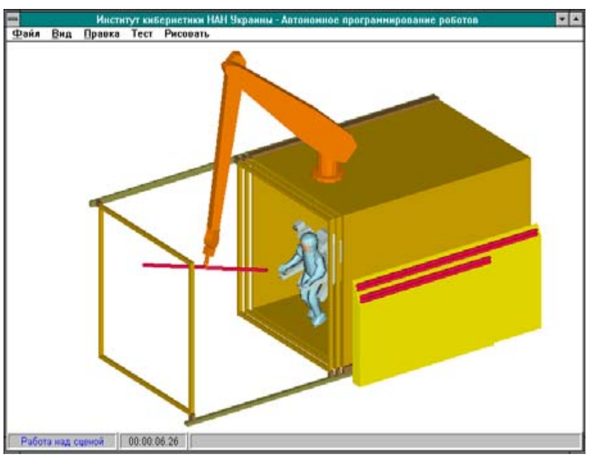

Fig. 10 The phase of the first part transportation.

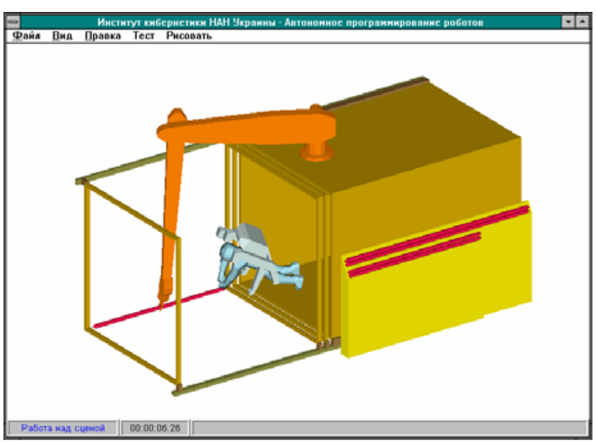

Fig. 11 The first operation of lock joint fulfillment

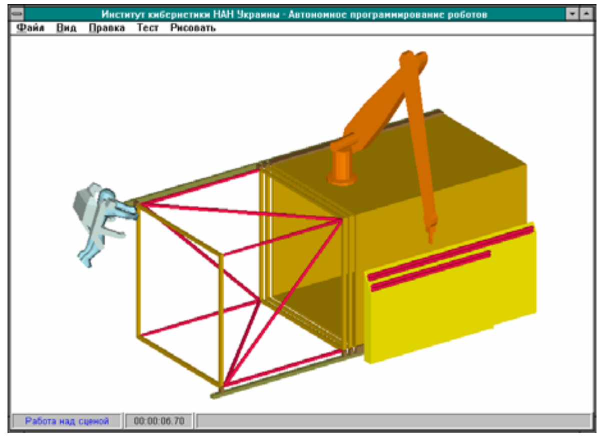

Fig. 12 The last operation of lock joint fulfillment

## 6 Conclusion

Rea-time data processing and minimizing data uncertainty are key problems of providing safety autonomous robots behavior. These problems solving among other relates to:

- Use of cooperative functioning robot subsystems;
- Development of the algorithms of sensor data processing and robot goal directed actions planning based on techniques of global optimization;
- Hardware and firmware algorithms implementation;
- Creating infrastructure for personal service robots

The future work will be directed to solving the problems of development of information support to multifunctional personal robots and to creating a parallel robot world and adjusting it with human being world.

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