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Modular Approach in Projecting of Intelligent Mobile Robots

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1. Problem formulation

The short history of robotics shows some similarities in the research, development, production and application of stationary and mobile robots. But there are also interesting differences between those two categories as the second one is much younger and learns from the experiences of the first. There is tendency of some saturation of the average year production of industrial robots in the last decade. In the beginning, robotics (with exclusively stationary robots) was growing mainly based on a continuous entering a new application fields (e.g. laser welding, assembly, laser hardening etc). Stationary robots themselves were continuously on the way of improving of their mechanical design, control systems and adaptability. Those becoming obsolete or amortized were taken out of the production lines even earlier than necessary. Using better and better cheap sensors and sensor systems, industrial robots become easily adaptable to a large variety of processes. The strong competition between robot manufacturers has led to a continuous decreasing of their prices and increasing the level of their performances. But new application fields for stationary industrial robots are limited.

There are three main streams in the development of industrial robots:

– sophisticated universal robots;

– simple specialized robots for specific operations (e.g. for arc-welding, spray painting, laser cutting etc.);

– modular robots.

Mobile robots are following the same development streams like the stationary ones – starting with sophisticated universal robots, than specialized ones and modular as an emerging group. But industry is not the main domain of the mobile robots. The first service applications of the mobile robots were very successful and soon the robotic community became aware of the great future of this new branch of robotics – service robots.

According to A. T o f l e r [4] and a number of other distinguished futurologists, in the 21st century mankind will enter the so-called postindustrial era and services will be the prevailing field of the world economy. We can expect that the field of robotics will be changed drastically in the 21st century. The number of service robot applications will grow much faster than this of the industrial robots. All this is expected because of penetration of service robots (stationary service ones included) in all spheres of human life and activities. In the beginnings of mobile robotics they were developments in the universities and institutes, mostly of a very sophisticated universal mobile robots for research, educational purposes and application tests and studies. Their development was very expensive and time consuming. Industrial Automated Guided Vehicles (AGV's) were the first practical applications of mobile robots. Today the universal service robots have little chance for a large-scale of production because of their high prices. In fact service robot applications started with introduction of some specialized service robots like robot-guards, floor cleaning, transportation robots, able to be used only for some specific tasks defined by their designers or by users. The specialized (single purpose) mobile robots are much cheaper than universal ones but we think that the best price-performance results can be reached only by modularization of the structures of mobile robots-much more valid for the service ones. Many designers and companies today will change their development and production strategies in mobile robotics towards modularization as to become more flexible and competitive in the market. Service robotics represent the prevailing part of mobile robotics field and it is very important to study all tendencies in their development.

2. Market review of service robots

The importance of robotics for the development of the world economy was understood by the United Nations quite in time and this field is monitored yearly. A study made by the experts of the United Nations together and the International Federation of Robotics [1] is covering the statistics, market analysis, case studies and profitability of robot investment. According to these studies the total word stock of service robots at end 1999 can be estimated at a minimum of some 6600 units. Estimated number of service robots by application areas, and forecasts for the period 1999–2002 is shown in Table 1.

Table 1. Statistics and prognoses for service robots [1]

Types of robots	Installations 2000–2003
Cleaning robots	700
…………………………………	……………
Domestic robots	40 000
Medical robots	5000
…………………………………	……………
Fire and bomb fighting robots	250
Robots in the construction industry Robots in agriculture and forestry Hotel and restaurant robots ***Clean-room robots*** Laboratory robots Space robots	500
Entertainment robots	
Other types	260
Total number of units, excluding vacuum cleaning robots	49 400
Vacuum cleaning robots	270 000
Estimated value in $ millions	2600

In our opinion some single purpose robots in this list can be replaced by modular mobile robots with a „tool kit“ of peripheral systems like robot arm modules, modular grippers, modular electrically driven tools etc. This yields to a quasi multi-purpose robot for: inspection robots, some medical robots, courier and mail delivery robots, robo-guards, etc.

3. Concept for creating of modular mobile robots

Most of mobile robots in use are service and single purpose robots. As it was pointed out earlier their development costs are smaller compared to the universal ones but their prices are not going down so much because, while in production, they cannot reach huge series. Of course there are exceptions like home vacuum cleaning ones, some categories of entertainment ones, etc.

Finding some good modular solutions, service robots will make their applications boom soon. Mobile Robot Platforms (MRP’s) are the early birds in the move towards modularization of mobile robots. Today some companies are producing MRP's which are quite alike- with the similar tree will locomotion system, cylindrical body, rings with sensors and some of them with an attached articulated robot arm.

From the designers point of view a "Mobile Robot Platform (MRP)" is a multi-use mobile robot, developed in its basic configuration and having all the most important and vital for its mobile functions systems.

Having the basic MRP realized with its main systems and functioning well, it can be upgraded or modified by adding a number of peripheral systems and tools for the performance of different tasks or functions. This type of modularization can help to reach a large number of applications using some combinations from the specially developed set of modules. For covering the need of MRP's with different load capacity and moving abilities it is necessary to develop some 2 or 3 sizes of a basic MRP's built themselves on a modular principle too. The schematic diagram of this approach showing a set of systems to be added to the basic configuration of a MRP for its upgrading is shown in Fig. 1.

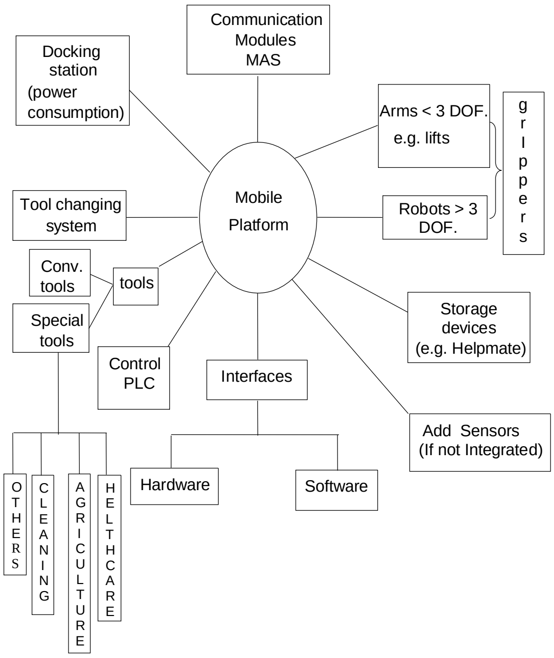

Fig. 1. Peripheral systems and tools

Very specialized industrial or service MRP's having only some of the systems shown in Fig. 1 as their onboard systems are strongly dedicated to a certain task e.g. floor cleaning, car assembling etc.

In such cases it is impossible to apply the principles of a basic configuration and its upgrading. Designers proceed directly to a design of a specialized MRP.

4. The “tool kit” of robot arm modules

Following the modularization strategy described above, a “tool kit” – a set of robot arm modules for use with mobile robots is under development. The goal of this design is to reach a “low cost” solution, modularization of the control system and software and easiness in assembling of different structures.

4.1. Mechanical systems of the developed “tool-kit“ of robot arm modules

The “tool kit” of robot arm modules consists of modules for relative translation (T-module), modules for relative rotation (R-module), wrist with two rotary joints, gripper, a base and mechanical links. Those four basic modules are sufficient for assembling of a variety of different robotic structures (like Articulated, Cartesian, Spherical, Cylindrical and SCARA type robots as well as a number of 2 or 3 DOF mechanisms). The motion of a carriage of the modules for relative translation is realized on the base of a stepping motor coupling with a trapezoidal threading screw. This screw drives the carriage by a split nut. The carriage is guided by two cylindrical guide-bars. The revolute modules are made out of a harmonic drive reduction gear that is coupled with a stepping motor. The reduction gear output shaft is coupled to a fork by means of ball-bearings. The working range of rotation can be adjusted by a set of cams. The coupling between two modules can be realized by screws. A quick disconnect feeder cable will be built as to ease combining modules.

4.2. Control System for the “Tool-Kit“

The general structure of the control system for control of the modules uses two hierarchical levels. A PC at the high-level and identical modules with micro-controllers on the low level. Each module will control one stepper motor.

The high level of the control will solve the direct and the inverse kinematics problem and will be planning the robot motion trajectories and communicate with the low-level modules of control. The task of each low level module will be to exercise a control of the stepper motor considering the actual commands and tasks for velocity, number of steps and direction of the motion, received from the high level. The link between the two levels of control (the computer and the controlling modules) can be made by using of a standard asynchronous serial interface RS 232. The operational system will consist of program package: interpreter of a specially designed high level language, programs for control of the stepper motors, program editor and data editor. The operational system will support all functions of the disc operational system.

5. Application examples

As it was shown above, the developed “tool kit” of robot modules will be quite universal. For different applications some single modules or combinations of them can be attached to the bodies of MRP’s. The easiness in assembling them together and the simple connection to the powering and control system will give possibilities to create many useful “low cost” mobile robot systems for performing of a variety of a tasks using the same type of MRP’s. In case of change of the production or service task of such already upgraded mobile robot system e.g. with a SCARA type arm, the late can be removed from the MRP and a more proper – e.g. articulated arm can be assembled by modules from the same “tool kit”. Generally in both of those applications the MRP should have sufficient level of artificial intelligence (AI) in its control and sensory systems as to be able to make decisions like e.g. obstacle avoidance, path planning and recognition, etc. In the application examples listed below we will assume that the MRP or the mobile robot (to be upgraded by our modules) is able to provide its part of all necessary functions for realization of the corresponding industrial or service application

5.1. Examples for production systems

- **Lift mechanism Assembly system.** The sketch of a system consisting of NOMAD 200 and a 4 DOF SCARA robot assembled by our “tool kit” modules and attached to its back is shown in Fig. 2. The system can be used e.g. for parts insertion on a long framed textile machines, railway carriages etc. during their assembly process. The platform should carry a palette or magazine with parts to be inserted into the frames. It must be decided how to realize MRP’s precise positioning at those large number of points to stop, the process of firmly braking of the MRP there and the relative precision of the mobile operation getting to the hole region. A SCARA robot structure was chosen because of its “selective compliance feature” allowing to adapt part’s axes with the holes ones, using their chamfer for the right start of the inserting operation. The design of the parts and the holes edges have to be foreseen for allowing the performance of this insertion easily and safely. For improving the insertion adaptability and the speed of insertion the SCARA robot should be equipped by a passive 6 DOF accomodator (passive flexible device in its wrist) and eventually with the tactile sensors for dosing the final insertion force and signaling for a release after the insertion is completed. Such approach can be applied also for disassembly operations in the recycling systems, adding the necessary equipment.

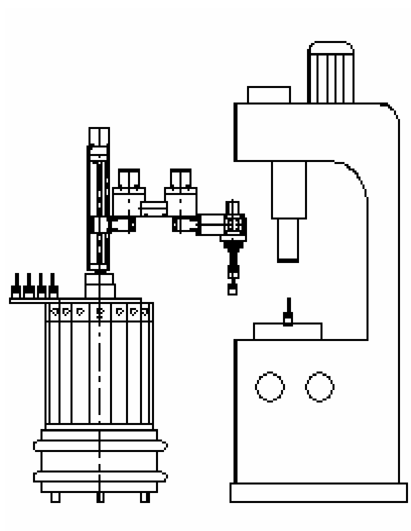

Fig. 2. Mobile rtobot for flexible assembly

The following parameters can be reached:

– load capacity up to 1 kg;

– positioning accuracy ± 0.5 mm (sufficient because of SCARA features and the RCC device);

– vertical movement/axis Z ± 200 mm.

5.2. Examples for service applications

- **Medical application.** A sketch of a system consisting of MRP NOMAD 200 equipped with an 5 DOF articulated robot arm built by our modules designated for performing a group of tasks of a medical care in hospitals is shown in Fig. 3. On the NOMAD's back it must be a fixed palette having a number of "nests" for safely placing there by the robot arm of a special hospital "glass pots" for transportation of medicines, specimens of patient's urine or some other medical items. At each patient bed -table there must be a region of the same type configured "nests" (holes) for safely placing those glass pots (either filled with medicines from the hospital pharmacy or other medical items and also for empty ones for getting patient's specimens). The articulated robot can perform picking the pots from the NOMAD's based palette and placing them to the corresponding patient's bed's tables "nests"(or vice versa) easily, provided the docking of the mobile robot is comparatively precise. Such mobile robot controlled by the main hospital computer can transport specimens, medicines, medical items etc fulfilling medical staff orders or patient wishes on a 24 hours duty cycle. Of course they have to be a number of such "MRP-couriers" as to assure the service tasks flow in a modern hospital. Such multi-agent system of course is a very challenging one but technically feasible today. We can pretend that such system (if properly realized) can be more efficient than the HELPMATE's one because the latter transports medical material and food around the hospitals but has not a robot arm. The availability of an articulated arm with gripper (having a set of build in intelligent sensors) attached to the MRP's body and controlled by its very intelligent control system can increase seriously the hospital service robot performances in the near future.

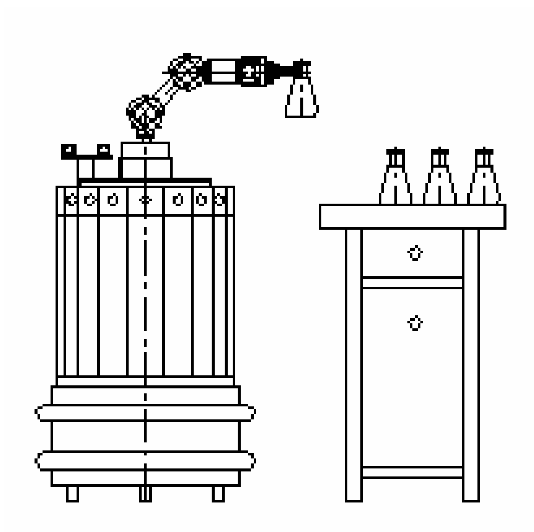

Fig. 3. Nomad 200 in a "Flexible hospital robotized distribution system"

- **Floor cleaning and polishing.** An application of a MRP Nomad 200 for cleaning and polishing of floor surfaces is sketched on Fig. 4. A linear module from our “tool-kit” is attached to the NOMAD’s body vertically by a connecting console (specially formed as to save the use of more modules), a rotational module is leading an electrically driven disc brush which is fastened firmly to it. By the linear motion “down”, the brush starts to approach the floor and cleans or polishes it. By turning the disc brush on 90 degrees the system can be used for cleaning or brushing of side stone or mosaic frames of the floor. The brush touch to the floor or frames with a certain preset force can be realized by using of a special tactile sensors build in the brush axe. If we will attach to the end of such arm an abrasive disc it can be used for stone or mosaic surface forming or polishing. A lot of other applications can be realized by using the modules of our “tool-kit” provided there is an intelligent MRP able to perform all the mobile functions intelligently and safely. If we will install at the end of an arm assembled by our modules a tool changing head and position a magazine of assembly tools on the MRP’s back, we can upgrade it e.g. to a flexible assembly mobile system. Another set of tools e.g. for plastic material forming can upgrade it as a flexible tool for the plastic constructions covering walls, building facades or for servicing them. They can be designed endless number of applications with those low cost simple and reliable modules. In case of amortization or defect of some of them the replacement with a good one can be a meter of a few hours. This is an important advantage for the users.

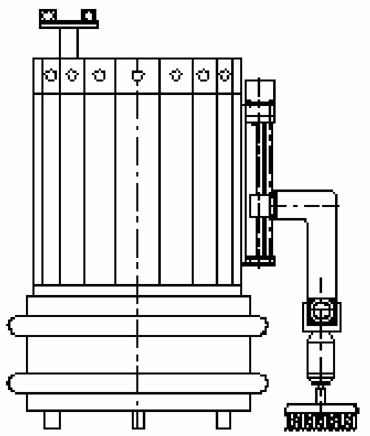

Fig 4. Nomad 200 as “Floor cleaning system”

5.3. 3-D modelling of the modular mobile robot system based on the projected “tool-kit” of modules

Mobile Robot Platforms usually have the form of cylindrical body moving on wheels. Their stability is as better as the mass center is lower to the floor and in the ideal case over the geometrical center of the base. Designers of MRPs are doing their best as to install all heavy parts (such as batteries, motors, drives etc) and modules in its lower part. When using MRPs as a basic unit of a Modular Mobile Robot and installing on top of them or on their body some additional equipment, robot arms, pallets, tanks with some fluids etc. we have always to fight for an optimal balance and stability.

Let us discuss the example of installing a cylindrical structured robot arm (assembled of modules from the projected "tool-kit") fixed on the upper part of the MRP NOMAD 200. For to achieve the maximal reach of the hand, the arm base have to be installed near to the edge of the upper "deck" of the MRP. Calculating the stability we have to know the mass centers of the NOMAD 200, centers of the base, modules building the arm and this of the (full) load.

The most modern way to do so is to use one of the existing computer programs for modeling of the modules, their assemblies and the modular system as a whole. They calculate the mass centers automatically. For the designers of Modular Mobile Robots it will be necessary to develop a library of computer models of all different modules available. This will ease their work substantially. Use of a CAD principles will shorten substantially the time for creation of new structures of Modular Mobile Robots and their applications.

Something more – the 3-D models of the "ready made" Modular Mobile Robots should be animated in a "real" operational surrounding as to "test" their functional abilities such as following the path, delivering items, avoiding obstacles, entering rooms, elevators etc.

As it was pointed above one of the discussed systems can be structured of a NOMAD 200 (available at IHRT) and Cylindrical Robot Arm built by our "tool-kit" of modules. This Modular Mobile Robot can be designed for performing of a group of simple tasks for medical care in hospitals like transporting of empty glass pots from the hospital laboratory to the patients bed-tables and back (filled with blood or urine specimens) to the laboratory for testing. If properly designed and organized such system can be very effective.

- **3-D Modeling.** Using CAD software program SOLIDWORKS 2000 we have made a 3D model of the system using the following parts:

Part Nomad 200 – Nomad 200 is a cylindrical bodied, 3 wheeled Mobile Robot. It includes in its basic configuration also the following important modules: Sensus 100^{TM} Tactile Sensor System, Sensus 200^{TM} Sonar Ranging System, and Sensus 300^{TM} Infrared Proximity System.

Part Translation module – T module includes 2 Panels, Cartridge, Screw, 2 Guiding rails and a Stepper motor drive. Wrist with a gripper will be connected on the free panel.

Our T modules have sufficient reach and if the column formed by another (similar) T module will be installed on a base over the upper part of NOMAD 200 near to its edge. Such cylindrical robot arm can pick and manipulate the described laboratory glass pots with patients specimens easy. For such simple operations a cylindrical arm is sufficient, simple and cheap.

3-D model of the Modular Mobile Robot structured of Nomad 200 with a Cylindrical robot arm – Manipulating system is projected for use in hospitals for transporting of patients medical specimens from and to their laboratories.
Fig. 5 Model of mobile robot Nomad 200 with cylindrical robot arm
Mass properties of the Mobile Robot Nomad 200 with Cylindrical Robot Arm:
Output Coordinate System : -- default --;
Mass = 94390.79 g;
Volume = 12182854.21 mm^3;
Surface area = 5721113.28 mm^2;
Center of mass (in mm): X = –226.46, Y = 143.36, Z = 729.34.
Principal axes of inertia and principal moments of inertia: (g. mm^2)
I_x = (–0.15, 0.03, 0.99), P_x = 2408577527.04;
I_y = (0.99, 0.02, 0.15), P_y = 11053864915.98;
I_z = (–0.02, 1.00, –0.03), P_z = 11125246420.63.

Moments of inertia: (g. mm^2)
Taken at the output coordinate system:
I_{xx} = 63002127567.87 I_{xy} = –3030502036.84,
I_{xz} = –14283338749.23,
I_{yx} = –3030502036.84 I_{yy} = 66167238212.88
I_{yz} = 9604674269.42,
I_{zx} = –14283338749.23 I_{zy} = 9604674269.42,
I_{zz} = 9399849669.36.

Fig. 5. Model of mobile robot
Nomad 200 with cylindrical robot arm

5.4. Animation of the modular mobile robot system based on the projected "tool-kit" of modules

3-D Studio Animations of a Modular Mobile Robot equipped with:
– Cylindrical robot arm
– PUMA type articulated robot arm for manipulation of a glass pots with patients specimens in hospitals.
–Translation module with disc brush
for cleaning and polishing of the floors.

3-D Studio MAX is the best selling software for three dimensional graphics and animation.
These days the computer generated graphics are widely used for different purposes – for technical simulations, game development, in the movie industry, etc.

3-D Studio MAX in particular is an object-oriented program created by "Kinetix" ("Autodesk's" subsidiary), which implements both, modeling and animation. In MAX there are different approaches to model and animate. Modeling methods are based on polygons, splines (bezier curves), NURBS (Non Uniform Rational Beta Splines) and Subdivision Surfaces. In a few words, modeling consists of creating, manipulating and transforming curves and control points describing an object. Also, there are a lot of ways to animate, but the most common used is the so called "key-frame animation" which presents an interpolation between two states. The interpolation is made by a "controller" which performs a mathematical function. MAX, like most other 3-D packages implements a hierarchical linking between objects, which has a great importance for animation, especially for mechanical animation. This linking can be: Forward Kinematics (FK), or Inverse Kinematics (IK). In FK transforming the parent object affects the child objects. In IK not only the child objects depend of the parent object, but also, transforming the child objects affects the parent. IK is a very important feature, which is widely used for animating of mechanical parts, or machines. In the first simulation, Modular Mobile Robot structured of Nomad 200 with a Cylindrical robot arm (see Fig. 6), we used FK to create the moving of the robot's manipulator and the other parts. In the second simulation Modular Mobile Robot structured of Nomad 200 with a Puma type articulated robot arm (Fig. 7), we found easier to use IK because of the human-like construction of the robot's hand. Both manipulating systems are projected for use in hospitals for transporting of patients medical specimens from and to their laboratories.

In third simulation Modular Mobile Robot structured of Nomad 200 with a linear module and attaching to it an electrically driven disc brush or mosaic polishing fine abrasives disc (Fig. 8), we used also FK to create the moving of the robot. This service modular robot is projected for automation of floor cleaning and polishing operations.

These simulations are just examples of the great potential of this method in future developments of Modular Mobile Robots, their modeling and animations as to reach optimal system's configurations and paths for performing of different operations. The animations will be demonstrated on the computer.

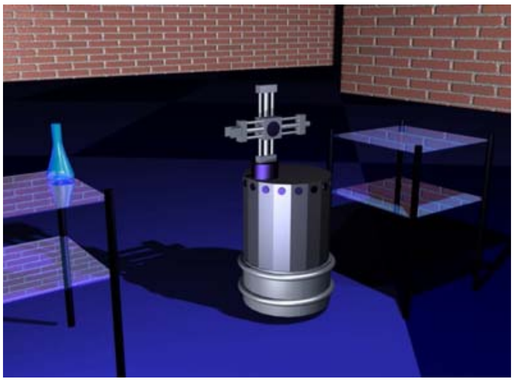

Fig. 6. 3-D animation of the MMR with cylindrical robot arm

Fig. 7. 3-D animation of the MMR with Puma robot arm

Fig 8. 3-D animation of the MRP with translation module and disc brush

6. Conclusion

The number of service robots in use today is very low. One of the reasons is only the availability of single-purpose robots developed for one distinct task. A new approach for projecting of a multy-purpose robots is described in the paper.

Modularization of mobile robots and especially of service robots is promising to open a wide perspectives for fast growing of their applications. It will lower robot prices, shorten the projecting time, speed the implementation of robotized systems and ease system‘s servicing.

The paper deals with the development of a „tool-kit“ of robot arm modules and the ideas for their applications with a standartized MRP‘s for performing of different mobile robot applications towards the idea of modularization in the field of mobile and especially service robotics. Some simulation and animation technics are described.

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Модульный подход к проектировании интеллигентных мобильных роботов

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(Р е з ю м е)

Число роботов в области обслуживания небольшое. Причина этого является их строгим предназначением для только одной цели. Новый подход в проектировании многофункциональных роботов описывается в статье.

Модульный подход к проектировании мобильных роботов и более конкретно роботов для цели обслуживания – область с большими перспективами. Он сделает цены роботов более привлекательны, уменьшить время проектирования и ускорить применение роботизированных систем.

Рассматривается развитие комплекса модулей роботов и их применение со стандартными системами для выполнения разных задач. Показана техника симуляции и анимации.