**ZRÍNYI MIKLÓS NATIONAL DEFENSE UNIVERSITY**
**PhD. Council**

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# DEFENSIVE APPLICATION OFAUTONOMOUS GROUND VEHICLES

(PhD) discourse
Authorial guide and official censure

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Budapest, 2009.

## The scientific problem

Nowadays, there is a big demand for the application and development of defensive, exploratory, information gathering robots. The American, 230-billion-dollar Future Combat System (FCS) project is the biggest technological research program in history. The central part of this program is the development of exploratory and combat robots. The aim of the project is to replace the one-third of the American army by unmanned remote controlled or autonomous robots by the year 2015. Experts claim that there are more terrestrial robots in Iraq today than British soldiers. In Afghanistan, this means more than 4000 terrestrial exploratory robots!

From this, it can be seen that even today numerous robots are doing various tasks in different areas, and this number will probably grow very fast. Robots could replace soldiers, thus making it possible to achieve a war without killing soldiers.

Most of the robots presently on the market contain rather sophisticated mechanical solutions, and are therefore capable of accomplishing a wide range of tasks by adapting to most extreme circumstances. Most of the applied robots function as explosive ordnance disposal robots, but there are also robots or robot systems which work in exploration, transport or attacking. These are typically remote controlled robots, and have no capability of independent decision making. Moreover, for the directing of these complicated, remote controlled robots, there is a need for professional personnel, and in this case, the application and the survival chances of the robot depend on how skillful, well-trained and experienced the crew is. In numerous cases, the controlling people have to stay within sight and are thus in danger themselves.

**Due to all this, it can be seen that there is a big need for development of systems which are relatively or completely independent of the abilities of the controlling personnel**. In industry, repairing and goods-transporting robots have successfully been used, and they are capable of working fast and efficiently in dynamic surroundings, among people. The technological conditions for the application of similar autonomous systems already exist, so the efficient operating of such a system is possible. In the case of autonomous decision-making robots, they are able to perform certain tasks independently (e.g. movement stability, dockage, navigation, obstacle recognition). With further increase of autonomy, the number of tasks performed by robots extends, so the operator can be a less skilled person, who merely gives the instructions and esteems the gathered information. In the case of autonomous systems, it is conceivable that a single person controls a whole robot system, thus increasing its efficiency.

In the case of Republic of Hungary, it can be said that there are great advantages of the application of terrestrial robots performing various tasks, for the purposes of army, police, or disaster recovery. **Using these instruments in areas which are extremely dangerous or not soluble for humans, results in substantial increase of abilities, and contributes to the protection of manpower.**

According to this, the innovation of autonomous, defensive, terrestrial mobile robot systems is a developing field in which our country must take part, in order to keep up with technological development in the world, and to avoid being subservient to countries which are producing such tools.

Besides all this, it should be taken in consideration that there are experiments in a few laboratories in the world for controlling autonomous terrestrial robots, but there have not been acceptable solutions for autonomous functioning itself, or independent work on a given task, which contains in itself independent navigation and block recognition and avoidance, independent information gathering and processing, and the problem of adaptation to circumstances.

## My aims in this research

1. The quest of existing applications of mobile robots, their examination and analysis. Drawing inferences on this basis, which can serve as **a starting point for developing a defensive autonomous exploratory robot.** I would like to emphasize that **my aim is the examination and development of autonomous robots capable of independent problem solving.** This aim surpasses the mere examination of simple remote controlled devices, both in its extent and complexity of certain questions.
2. **To determine specifications for the carrier platform, electricity supply, in connection with sensors and controlling systems**, by the analysis and examination of terrestrial robots' system buildup and the survey of main functions. On the basis of all this, my aim is **to set up a general requirement system** for defensive autonomous mobile robots.
3. Furthermore, my aim is the examination, modeling and realization of possible ways of developing a **controlling device which can be realized in practice.**

4. **The examination of a docking system** which is simple, reliable, achievable with the help of a camera positioning system and can be used in the case of an autonomous robot system.
5. To make a proposal for **creating a defensive mobile robot system**, which can be operated economically in our country.

## I applied the following research methods in this work

I did extensive research work in order to collect and systematize information in connection with terrestrial autonomous mobile robots. I extended my theoretical knowledge essential for the achievement of my research aims by studying the publications accessible in the bibliography and on the Internet. I found it crucial to examine the practical realizations of the theoretical propositions set up during this research, so I created models of several systems and by examining the functioning system I supported my propositions. I got acquainted with different fields of mobile robotics research both at home and abroad. I participated in numerous scientific conferences connected to this topic at home and abroad both as a lecturer and listener. I published my research results regularly in professional publications and scientific lectures, and in the form of slide presentation.

## Examinations performed

For the sake of achieving the set aims I built my dissertation from the following chapters:

## Chapter 1

I defined the basic notions in connection with mobile robots. I examined the terrestrial mobile robot systems applied in our country for army and civil purposes, and more specifically I discussed the buildup of Andros F6A heavy explosive ordnance disposal and the Telemax light weight explosive ordnance disposal, and the SWISSLOG LTC2-FTS robot system located in the State Health Center. As a further step I analyzed the various terrestrial mobile robot devices applied presently in the world, such as the exploratory small-sized platforms (iRobot Packbot, Autonomus Solutions Inc. Chaos), bomb-disposal robots (Packbot EOD), combat robots (Foster Miller TALON SWORDS,) goods-transportation robots (Boston Dynamics Big Dog), unmanned target vehicles, scout robots. I also discussed the possible applications of robot groups, the usefulness of robot convoys, and I studied the expectancy of spreading tendencies of robots in the world on the basis of reviewing the current developments going on in the world. Besides discussing mechanicly developed platforms of various sizes and applications, I also analyzed and estimated these, and created a general requirement system applicable to terrestrial autonomous mobile robots, in which I examined the mechanical buildup, the energy supply, the control system, the sensors and actuators and the communication demands.

## Chapter 2

I reviewed the system buildup of defensive terrestrial mobile robots, the possible realizations of main function tasks, I proposed the specific buildup of certain functional parts. In this chapter I first discussed the structure of platform, and I analyzed the characteristics of robots which imitate forms of movement from the natural world, wheeled and caterpillar robots. The following step was analyzing the field of energy supply. Among the possible solutions for energy supply, I discussed the following: batteries, fuel cells, internal combustion engine generators, and the renewable energy resources. The next topic was the drive of mobile robots by various electric and internal combustion engines. After this, I looked at sensors applied on the board of terrestrial mobile robots. In several cases, I proved the application of sensors by pragmatic measurements, and thus for instance I found out that the 2 dimensional distance measuring sensor which works on the principle of triangulation cannot be used in real dynamic surroundings, but only in experimental laboratories. Furthermore, I discussed the possibilities of sensor fusion. I also discussed useful load on the board of mobile robots and looked at the communication between the operator and the mobile unit.

## Chapter 3

I analyzed the possible buildups of control units on autonomous robots. For the sake of examination of my three governing principles for development (customized robot controller, embedded PC- based controller, and industrial PLC- based controller) I discussed the process of building three experimental robot devices. By analyzing models that I built, I examined the time needed for certain solutions, their flexibility, achievement, reliability, and cost. With the help of the models, I proved the applicability of industrial components in mobile robotics. I gave detailed discussion of main parts of a controller built up from industrial components, and the functioning of the model. I dealt with the central control unit, the drive modules, the industrial solutions for energy supply and communication, and I reviewed the functioning of the controller program, and the main algorithms which control the working of the robot. Also with the help of the models that I made, I proved that a camera positioning system that helps docking can be constructed, a system which is able to help the location of a defensive terrestrial mobile robot on a specific position.

## Chapter 4

I set up a system of requirements for a defensive territory security terrestrial mobile robot system. In these requirements I specified the following: mechanical buildup, drive, energy supply, guidance, navigation, block recognition, sensors and communication. I also defined the additional elements needed for the efficient functioning of a mobile robot system. Furthermore, I proposed a possible practical application, on the basis of the previously mentioned requirement system. This application is capable of completing the defensive tasks of a military base, in an autonomous way. I made a proposal for the appliances that can be used for the military autonomous security robot and I examined the features and prices of necessary components obtainable on the market. After collecting the appropriate appliances, I analyzed the time needed for the development of the whole system, its flexibility, capabilities and costs.

## Summary of inferences

In my discourse I defined the basic terminology in connection with terrestrial mobile robots and researched the important applications of these vehicles at home and abroad. I came to the conclusion that the mechanical buildup of present-day terrestrial mobile robots is extremely sophisticated, but the robots presently in use in Iraq and Afghanistan are all remote controlled. The next step in the development is improving the autonomy of vehicles, since in this case the operator can handle the robot from a safe place, which is outside the operational zone. In the case of an autonomous system, one operator can handle more vehicles. Thus, his task is simply giving out commands, and evaluating information, which makes it possible to have less trained operators. The DARPA Grand Challenge and Urban Challenge competitions prove that with today's technological development, it is possible to construct a viable autonomous mobile robot system, which is capable of adapting to a real dynamic human surrounding.

Closely connected with the question of autonomous mobile robots is the possibility and necessity of teams of robots. Just like a single soldier is not able to fulfill every task, a single robot cannot be capable of doing so. I proposed the idea of applying robot teams which communicate and cooperate with each other and thus share tasks, in this way making it possible to improve the abilities of the whole system.

I examined and discussed the robot devices used in our country and abroad, and then I drew general conclusions about mechanical buildup, energy supply, operating system, sensors, actuators, and communication. These conclusions should be taken into consideration during vehicle planning and construction.

After researching and analyzing the currently applied robot systems I came to the conclusion that the best possible buildup for autonomous terrestrial robots is the form of macro and midi robots.

Judging from the testing results, it can be said that unless the extreme field circumstances make it impossible, the most appropriate buildup is that of a wheeled robot, since it is capable of greater speed, and it needs less energy than for example a stepping structure. If the slipping of the wheels on the ground can prevented (by intelligent traction control systems and gradual speeding and breaking), the moving measured from the wheel shift gives fast navigation information to the operation equipment.

I proved by an experiment that a two-dimensional distance measuring can be realized by a triangle method, but this measurement method is extremely sensitive to light circumstances and quick change of the environment, so I concluded that this sensor can be applied only in laboratories for experimental purposes. On board of terrestrial mobile robots it is necessary to apply distant measuring sensors based on running time. Therefore, I would suggest the application of a laser scanner as the vehicle's navigation and block-detecting sensor.

I proved that using a single sensor cannot be the solution for fulfilling the tasks of navigation and block detection, and the solution to this problem is comparing and incorporating the signals of more sensors.

As the mobile robot has to carry its own energy supply with itself, the weight and size of the energy supply unit seriously affects the size and speed of the robot, and the stored energy affects the deployment range. After researching the possibilities, I can claim that the best energy density and power to weight ratio can be achieved by internal combustion engines, but their noisiness and the heat they emit renders their application more difficult or in certain cases even impossible, since the robot can easily be detected. In my opinion, the usage of fuel cells would mean the ideal solution, since similar to the internal combustion engines, the cell is capable of providing energy as long as there is fuel available. The recharging of the fuel is a fast process, so the system's service time is long. However, the fuel cells are not widely spread so far, their price is high, and it is difficult to find them on the market. If there is no opportunity for the application of expensive fuel cells, or the task does not justify their usage, the Li-polymer battery provides a good solution.

The most important part of an autonomous vehicle is probably the decision making control unit, and its peripheries. In the third chapter, I examined the features of three different control units, and I concluded that the application of a modular control system built up with an industrial PLC is the best fitted to the control of defensive terrestrial mobile robots. The modular buildup results in a flexible system, and the time of hardware development decreases almost to zero. The usage of a controlling system which is tested and suits the industrial standards improves considerably the reliability of the whole system.

In the buildup of the control system, I established three possible developmental directions. The first one is the customized microcontroller or the FPGA based system buildup, the second is the embedded industrial PC based controller, and the third is the industrial PLC based control system. I assessed that in the case of small production series the most suitable solution is the industrial PLC based system, because their application makes it possible to create an extremely flexible system, without hardware development. The industrial instruments meet strict standards and reliability criteria, and by their usage a higher reliability can be achieved, that by the application of customized devices. The price of the industrial tools is high, but in the case of a small production series both engineer hours and development time can be saved.

I proved the adequateness of using industrial devices in mobile robots by creating and testing a universal PLC based mobile robot controller and thus I also proved that a complete mobile robot control system can be built from devices taken from companies which produce industrial components. During my research I developed a flexible, universal robot controller which can be used without hardware development, on the deck of terrestrial mobile robots. This universal controller is capable of controlling optional ground platform, and of receiving sensor signals. An advantage of the system is the modular buildup, since by connecting the suitable modules, the system can be applied on various platforms.

During the additional development of the model I examined the possibilities of docking, and I created an image processor system which helps docking, whose operation I proved by testing. The image processor system is able to recognize and determine the position of a symbol which is placed to the robot's board, so the navigation necessary during docking can be performed by a camera posing system located above the docking station.

On the basis of the general requirement system I proposed the building of a real military terrestrial autonomous mobile robot system. The system can protect and superintend a military area. By specifying the devices necessary for controlling, navigation, and actuation and by choosing practical devices, I examined the main parameters of the system and the costs of the development.

## Innovative scientific results

1. I examined and analyzed the types of robots used so far in our country and in the world, and on this basis **I scientifically established the general aspects and criteria necessary for designing a terrestrial mobile robot system.**

2. After giving an overview of the system buildup of ground vehicles, **I proposed the specific buildup of carrier mechanics, energy supply, sensor systems, and control system for a terrestrial mobile robot.**

3. I built and tested the operation of an industrial PLC based autonomous mobile robot controller and concluded that with it, a flexible and reliable robot controller can be constructed. Within a short developing time and using industrial devices, a central controlling system of a mobile robot can be realized. **With all this, I proved that a flexible and very reliable robot control system can be designed with the help of industrial devices.**

4. I created a camera positioning system model and by its testing **I claimed and proved that the crucial act of docking of terrestrial mobile robots can be solved by a camera positioning system in a fast and safe way.**

5. On the basis of the system of requirements that I had set up, **I proposed the building of a defensive mobile robot system.**

## The recommendations of the discourse

The terrestrial mobile robot system that I designed is recommended for the guarding of military areas and borders, as well as for the indoor and outdoor area protection, so I would kindly recommend my discourse to the Hungarian Army and Hungarian Police. I would like to recommend the practical realization of a similar system, and its application as a territory security device for ENSZ or NATO missions abroad.

The system can also be used for the protection of civil establishments, and for goods-transport inside institutions.

The rapid development of mobile robotics makes it crucial to integrate mobile robot systems into education. Therefore, I also recommend the discourse to institutions of higher education which are engaged in teaching and developing autonomous mobile robot systems.

## Publications:


*Proofread articles:*

1. **Autonóm mobil szárazföldi robotok helyzete és alkalmazási lehetőségei a 21. században,** Robothadviselés 5. Tudományos Konferencia 2005. nov. 24., Bolyai Szemle 2006, XV. Évf. 1. szám p. 204-217, ISSN 1416-1443
2. **Zárt térben használható földi mobil robotok navigációs és akadályfelismerő szenzorrendszerei, a beltéri navigáció lehetőségei**, GÉP A Gépipari Tudományos Egyesület műszaki folyóirata, 2006/5 LVII. évfolyam p. 29-36. ISSN 0016-8572
3. **Moduláris felépítésű mobil robotikai alkalmazások kialakítási szempontjai,** Hadmérnök I. Évfolyam 3. szám - 2006. december ISSN 1788-1919
4. **Autonóm szárazföldi mobil robotok térhódítása**, Hadmérnök II. Évfolyam 1. szám - 2007. március ISSN 1788-1919

*Hungarian articles:*

5. **Intelligens szárazföldi mobil robotok napjainkban**, Metagalaktika 2007 v9.5 p.186-191. ISSN 0209-9934
6. **Zsűri különdíjjal tért haza a BMF Kandó csapata a Design Challange 2007 nemzetközi robotépítő versenyről,** Hadmérnök II. Évfolyam 2. szám - 2007. június ISSN 1788-1919

*Proofread foreign articles:*

7. **Sensors For Mobile Robot Systems**, Academic and Applied Research in Military Science, Volume 5, Issue 4, 2006 p.645-658. ISSN 1588-8789
8. **Industrial Component-based Sample Mobile Robot System**, Acta Polytechnica Hungarica, Volume 4 Issue Number 4 2007 ISSN 1785-8860

*Conference publications:*

9. **Introduction to Mobile Robotics** XXIIIth Kandó Conference 2006 ISBN 963-7154-42-6
10. **Industrial Modular Structure Mobile Robot Application** Proceedings of 16th Int. Workshop on Robotics in Alpe-Adria-Danube Region - RAAD 2007 Ljubljana, 2007, p.413-418. ISBN 978-961-243-067-2
11. **Modular industrial mobile robot systems, mobile robot docking** XXV. International Wissenschaftliches Kolloquium Schweinfurt 2007 Konferenciakaidvány
12. **Experimental mobile robot system built up from industrial components** 8th International Symposium of Hungarian Research on Computational Intelligence and Informatics Budapest 2007 ISBN 978-963-7154-65-2
13. **Mobil szárazföldi robotok hordozó platformjának kialakítási lehetőségei** XXIVth Kandó Conference 2008 ISBN 978-963-7154-74-4
14. **Szárazföldi autonóm mobil robotok vezérlőrendszerének kialakítási lehetőségei**, Robothadviselés 8. Tudományos konferencia 2008, *Kiadvány megjelenés alatt.*

## Professional CV

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Budapest, 20.02.2009.

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