Using Model Robots in Research of Robot Cooperation Based on Multi-agent and in Education

PhD Theses

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Introduction

Several thousand years have passed since the appearance of Architas wood pigeon till Marco Dorigo robot swarm, but the man still interested in physical tools that facilitate the design and production of the work, or completely replace him in the course of work. Already in the Middle Ages were identified the idea of using a group of robots cooperating that war on our behalf, such as, Leonardo da Vinci robotic horse team plans. In recent decades an important area of research is, that how to replace a high quality mobile robot to work a large number of "low-cost" mobile robots. These robots can operate together more effectively in potentially contaminated or unattainable areas by human, they can discover and explore unknown areas, and can be used for military tasks which individually would not be able to solve. The swarms of robots and robot teams (the two terms do not mean the same concept) can be used in many other areas like medicine, emergency management, delivery, etc.. Natural desire is to increase the mobile robot swarms’ and groups’ size and to simplify communication between entities. Must made each robot to be able to gather information in their environment by a system and about this can be mapped - even for a robot - an internal image, define their position on a real or artificial background, and be able to coordinated joint work, co-operation according to a regular basis, or even self-organizing way. Pursuit of some of the research is that the cause of loss (damage, destruction of enemy etc.) task of such a system of robots will automatically take over other robots, thus ensuring the original tasks, targets.

Each chapter of my dissertation, processed literature procedures and theoretical methods worked out by myself, has been tested not only in simulators, but were adapted to actual robot model. Model robots are relatively low cost, their active and passive sensors are not very accurate, shells made of plastics, i.e. they are not applicable in such places, where the environment is too hot (eg. fire simulation), but they are well suited to model algorithms in the theoretical literature, and procedures developed by myself,. As usual, therefore, these robots are called model robots. Mainly NXT and RCX robots dealt with by forming groups of robots. I have worked out the increase the number of individuals in individual groups, despite the limitations of Bluetooth communication master-slave basis. Developed a method of in a more precise navigation of chains organized robots according to communication, it makes the robot group can explore more areas. We've created a space explorer method that gives the
traversal algorithm in either artificial or with wall-like obstacles areas within the chains organized robots according to communication.

According to researchers, senior IT manager academics in the second decade of the third millennium the same "explosive" growth is expected in the household, entertainment, scientific and military purposes, robotics, such as rapid change was in the number and the development in the quality of computers in the last decades of the second millennium. So that new generations of Hungary anticipate this robotic revolution, it is essential to introduce even now the presentation of robots, construction material and the teaching of programming options in the primary, secondary and tertiary education of information technology. For these reasons, such as dealing with young people, working in IT at a college as education teacher, in the 6th thesis chapter I will show that how in the previous sections of research and practical tasks using robots can be used in education especially the education programming.

In the introductory sections of each of the chapters of the thesis I review the topic-related scientific research and the results so far. In the second chapter I summarize briefly the essential concepts that are necessary in order to make an effective design the communication cooperation and coordination of mobile robot groups and robotic swarms, further to expand the boundaries of the system, and I introduce food-gathering function which I will discuss in a later served as the starting point of my experiments. In the third chapter using NXT robot groups I present, how to increase the number of robots through making specific communication channels. In the fourth chapter with using odometric proceeding, compass sensor and non-sensor for measuring wheel, I worked out a method that allows for more precise navigation in a simple model robots. In the fifth chapter I describe a new procedure which with help in Section 3-4 developed communication protocols and the navigation of robots, can create more robust robot teams to solve space exploration, with communication constraints and other coercive conditions, accessibility, and in areas with wall-like obstacles. In the sixth chapter, I show how the robots used in the previous sections are used in programming education, particularly in student motivation and improve self-concept programming.

1. Objectives

In summary, in my thesis I wanted to solve the following problems.

- To increase the number of entities in groups of not holonomic, and Dual NXT robot, composed of a multi-agent based robots, with producing the necessary for improving
multi-hop communication networks (Piconet, static scatternet), channels. The finished procedures are implemented for model robots.

- With help of created in the former communication networks, I organized the co-ordination and co-operation between the individual robots that is important in the point of the whole system. I introduce in practice a special, fauna adapted for the food gathering habit as robot groups model in "in artificial area".

- With the help of sensor fusion of a compass sensor and steering sensor, as well as combining the odometric process, I prepared an increased the accuracy of positioning procedure, eliminated navigational problems, so the model robots can be capable to solve based on multi-agent tasks as well.

- I created an area exploration algorithm in obstacle-free area and detect areas with obstacles, and I compared the proposed algorithms with two reference algorithms (algorithms Rooker and Birk).

- I introduced the model robots used for this purpose and new ways in education information technology programming for students. I examined the impact of introduced instruments, and demonstrated their positive effects to the programming self-concept and to motivation in the subject area.

2. Applied equipments and methods

Many researchers use computer simulation of intelligent agents for scientific investigation and research efforts. Many people use for this purpose, the Webots mobile robot simulator, simulator, or Repast general agent simulator or the Matlab program. The simulated procedures in most cases inexpensive and can help in the preliminary examination of a problem, and standing the hypotheses. The simulators despite of their numerous advantages can not substitute, but complement the real robot experimentation. During the real experiments progress, a number of "disturbing" factors may be incurred, which in the course of the solution with the simulator can be easily ignored. During my work in the robot group cooperation and communication and in testing navigation problems, model robots were used. With these real, not holonomic mobile robots (NXT, Dual NXT), in artificial environment real physical world modeling simulations experiments and measurements was carried out. The developed theoretical methods applied to real robots have raised a number of new problems, which can only be used in simulation programs had not been discovered. , I adopted to model robots the methods used in the scientific literature, as well as procedures and algorithms created by myself. For the robot control program, I used a C-based programming language, NXC programming language.

In the last chapter of the thesis, I studied how to use in the previous sections mentioned, relatively low-cost, programmable model robots in programming education. During training, NXT and RCX robots are used, the robot control programs are written on NQC, NXC and NXT-G language. For testing the hypotheses, we organized a monitoring control group. To
measure the programming knowledge and skills, 15 of item-test was used (Cronbach's \( \alpha = 0.86 \)). During the front and last measure the same measuring device was used. For the attitude towards programming and programming self-concept testing, a questionnaire containing 17 questions was used. The majority of the five-level questions, Likert-scaled response options included.

3. Scientific results

During my research, the model-robots were available, which features (navigation accuracy, communication skills) are not allowed to use them in a multi-agent based robotcooperational research. The NXT robots, for communication among the robots, a Bluetooth communication system is used. Based on the Bluetooth Piconet communication network is only one master and up to seven slaves can contain of, but in our case, where NXT robots are used, this limit is still limited because of the original NXT application of the network is only one master and three slaves were used. Therefore, in the T1 goal was expressed to establish and adapt procedures to model robot teams, that allow to increase the number of communication point within the robot group in each communication link of the robots, then how to define the tasks for the increased number of robotic group and coordinate them, and finally, how to control and navigate the individual robots, and further the entire group better.


T1. Communication abilities and navigation accuracy of simple model robots can be greatly increased, that can make them suitable for complex, multi-agent-based navigation and area exploration tasks.

T1.a. Robot teams, despite being simple and limited (1 master and 7 or 3 slaves, slow connection) communication link (eg. Bluetooth) are provided, with creation of “static scatternet ”Dual Bluetooth or radio communication network (tree, chain, ring topology) the number of robots may be increased within the robot group in communication with each-other (and, eg. implementable NXT robots).

T1.b Only odometry navigation using, with a small robot navigation precision (eg. in NXT robots 1.05*E-1 accuracy in a straight line) accuracy, using compass sensor and sensor fusion method the navigation accuracy (eg. NXT robots for 3.5 *E +1 - times) can be increased.

T1-a. Based on the idea a scatternet networks, I managed to make procedures for NXT robots that a master of a network enable to shut-down from itself robots (communication
wise), and others can connect to. In this type of network opposite to an ad-hoc scatternet network, the position of nodes with communication point of view is given, since it is only the master, that can switch on or off another robot. As a result this network is capable to send and receive both of unicast and broadcast messages, but the nodes and the nodes connected to the communication network entities have fixed place. Such networks are called static scatternet network.

Using of my procedures I developed the procedures of increasing the depth and width of the network and implemented them to NXT robots. With using this procedure in setting up a group, broadcast messages can be sent for all members of a robot group. In my test of a 3-level network (13 robots) a broadcast message from the master to all other robots took 30-55 seconds.

Critical points of the method were examined and I found that the former method has one critical point, the structure and breakdown of relationships. This can be created by software programs written by me, but the procedure is relatively time-consuming.

To improve the robot team members and to reduce the communication time, a different method was used with dual NXT robots. A Dual NXT is a robot, in which two robot bricks connect by physical cable and two independent Bluetooth radio systems can be. I proved in practice that a dual-radio-based sensor networks Bluetooth scatternet ad-hoc sensor group recommended by Sohrabi and his partners, and Leopold and partners, is useful in robot groups as multi-hop communication network. With Dual NXT robots a secure scatternet network can be built in which there is no need to switch on and off a "bridge" a robot. The network protocol has been written in the mentioned NXC language. With this method, with dual NXT robotic systems, a variety of communication network topology is built up, which the participant model arbitrary number of robots can be increased by maintaining secure communications.

**T1. b.** An intensively researched job for robot group is to entrance and detect an unknown territory. During the entrance a territory the robots can search for things, objects, “form map” or even a mobile phone and create links placed on the starting point another phone. In this case, not objects but one text file is "delivered" by the robot from one point to another over Bluetooth. (Response and detection of the object is not the task of this section.) In our system, in solving the task the robots organize in chain so that during the execution of their task their place in the communication chain is constant. The task is to "detect" a relatively large area so, that the communication chain traversal is not interrupted even for a moment. For these tasks the area should be divided into cells.
In these types of tasks it is very important to determine the exact position of the robots, respectively the precise control of the robots. If two adjacent robot for the poor control are so far away from each other, such the Bluetooth connection is lost, then the relationship is very difficult to be rebuilt, so in the following sections we examine and compare several methods in the accuracy of the navigation of robots point of..

**The control method to solve with odometric procedure**

During measurement series I concluded that with this method alone the control is not feasible, because after 20-30m going the robots will vary significantly from the original direction, so the distance between them is greater than it is allowed in the maximum Bluetooth communications. The robots navigation accuracy reached 1.05*E-1, which is not suitable for solving multi-agent-based robot-cooperation tasks.

We used sensor fusion method, wheel rotation sensor, compass sensor and odometric method.

From the former process keeping the wheels synchronization, the robot is completed with a compass sensor. In the process, the robot program has stored the value of the initial angle (\(\lambda_b\)) and then synchronizing the wheels moved towards the target. If during the progress the current direction (\(\lambda_a\)) the original deviation reached 1 degree angle from the original one, the robot suspended synchronization between the wheels of and turned the right wheel until the \(\lambda_b - \lambda_a = 0\), the value was.

The measurements showed that the robots deviation in the expected direction of 20m at a distance is not too high, since the robot navigation accuracy is up to 3.0*E-3, therefore this method is well suited for coordinated control and more accurate tracking of a robot swarm moving in larger area.

We can conclude that the low-cost model robots communication and navigation capabilities have been increased to such an extent that became suitable for complex multi-agent based implementation of tasks, such as the area detection algorithm performance is presented in T2-thesis.
2. Thesis


I've built an area exploration algorithm, which is recommended for a fixed-ended and in chain organized robot group, in them the communication is endless, and this algorithm is optimal in obstacle-free area, which discovers all the available area in the emergency conditions, within the minimum of time. It is well-suited in detection for wall-like obstacles areas as well.


The T2.a area exploration algorithm can be implemented well for in the T1 described in chain organized group, consist of 3.00 * E-3 precision navigation dual NXT robots.

With my research fellow, we created an area exploration algorithm that enables to be explored and discovered an unfamiliar area by a robot group starting from a base station, and as the communication, it is a chain-like group. Compelling reason, that they must solve the task that the distance between neighboring robots can never overcome the Bluetooth maximum distance. The function of the algorithm is, that a group, consisting of N numbers robots, starting from a basis station, and paying attention to the endless communication constraint between adjacent robots, discover the largest possible area within the smallest possible time so that a communication link with the base also consists of fly above. Retaining compulsory condition, the algorithm is extended to condition in which the boundary line of each cell of the wall-like obstacle the robot can be impeded.

Feasibility of the algorithm we tested with Matlab and a robot simulator, and with seven dual NXT robots as well.

Based on the results of the tests of the implemented communication link, the following conclusions can be drawn:

With a simple proof it can have been shown that the proposed (fixed chain-like team) exploration method is optimal in obstacle-free case, under the pressure of maintaining the relationship with the base station. Tentatively, we demonstrate that in the comparison of the proposed method and the cost function based methods.

The recommended algorithm achieves better detection time in low obstacles densities, and in 75% or 100% of detection rate, than a reference method (decentralized cost function and based on MANET). Positive feature of the process even in an area is not accessible, is due to the fact that there is a "leader" of the robot group and the leader robot stepcost overrides
(preference to enjoy) the rest of the robotic in area exploration strategy. Therefore, this method avoids the impression that the intelligence on individual goals of each obstacle hinder each other, that is characterized in a connect-forced, decentralized, cost function based methods feature. On the other hand, there are good properties of the proposed method in comparison with decentralized processes them. (They may be more robust and faster in an area with a lot of random obstacles.) Therefore, future work may consist of developing a hybrid method of both types (which I recommended and the decentralized procedure) benefits are included.

The collision avoidance strategy built into the algorithm helps the use of a special detect in simulator or in a real environment, because while in theory the robots to be considered as point-like individuals, practically they have real extension (Dual NXT 22x18x14 cm).

The rescue procedure built into algorithm is allows the robot group to continue detection process in case of a robot failure. The procedure treats differently, when, a robot fails at the end of the chain (Robot Head), in the middle of chain, or on the base point.

We introduced the recommended reliability and feasibility of procedure with a robot simulator in a obstacle-free and building-like environment.

Our proposed algorithm is implemented also in real Dual NXT robots, and tested in unobstructed and low-density obstacles areas well. The robots operated in the collision avoidance process and chain-rebuilding process the case of break as well.

In the third thesis, I examined how the model robots mentioned in two above thesis, to apply in college education, mainly in programming education.


The programming self-concept and subject motivation can be increased significantly by using the model robots in teaching programming for beginners, but they have no significant positive impact in the a short-term in the abstract programming knowledge developing.

The technical higher education has been detected in a significant number of students to develop programming skills are not as expected. In this context, the subjects noticed an increasingly shrinking as well. To confirm our experiences, the empirical survey was conducted, the results of which confirmed that new methods and tools are required to apply to the subjects in a more effective education. I wanted to put in place the tools in education to boost student motivation, and education can become more visualize, more practical, more interesting.
The effectiveness of knowledge transfer in the field of programming is determined by teaching students’ fundamental interest, motivation, attraction of the lessons. The model robot programming allows to students that to prevent the use of the skills level of experience opposite during traditional programming immediately required abstract thinking. This step facilitates the development of skills, deepening the level of understanding.

To justify my hypotheses, a short-term (4 months) control group measurement was made. Input level of knowledge of students, subjects' attitudes, self-image programming control was measured in a test using a single questionnaire. The measurement was performed at the beginning of the study, and about the same questionnaire and test measured the output level at the end of the course. For measuring the programming knowledge and skills a 15 items test was used. Testing the attitude towards programming and programming self-concept, a questionnaire containing 17 questions was used. The majority of the questions included the five-level questions, Likert-scaled response options. Patients in the control group and the experimental group were set up, as according to the input measurements, between the results of the two groups is not significant difference. The experimental group used in a new framework of subjects the learning of programming, model robots that can be programmed and the control group selected the conventional learning programming.

**The evolution of the two samples**

Important differences appeared in motives. During the semester the experimental samples of students were absent significantly less than the control sample of students ($\chi^2 = 3,22; \ p = 0,03$). The experimental group found much more enjoyable learning the subject ($x_e = 3,47; \ x_c = 2,96; \ t = 3,87; \ p<0,01$), than the control group, they found the curriculum less difficult ($x_e=3,07; \ x_c=3,35; \ t=1,96; \ p=0,03$). The teacher's attitude toward a subsample did not change ($x_{pre-e}=4,03; \ x_{post-e}=4,06; \ x_{pre-c}=4,03; \ x_{post-c}=4,12; \ significantly$, the differences are not significant).

In the control group the average programming self-concept is stable during the semester ($\ x_{pre} = 46,3 \ %; \ x_{post} = 44,1 \ %; \ t = -0,45; \ p = 0,66$). However, the test shows a significant change in the self-image programming model ($\ x_{pre}=47,2 \ %; \ x_{post}=52,2 \ %; \ t= -2,60; \ p = 0,01$). The difference of the changes in the distribution of the self-image of the two sub-samples can be observed. This result shows that despite the short-period, using new tools and methods result significant advance in the self-concept. This is important in terms of further learning, a developed self-image has a strong influence on the performance of students for further education.
Further monitoring of students is to verify real effects on self-concept development of additional programming effectiveness. About how this effect is sustained and how deep can help in future programming education, we can experience after a longer period.

4. Scientific publications cited in the thesis

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Author's other publications

