Mobile Robotics in Education and Research

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1. Introduction

Mobile robotics is a new field. Mobile robots range from the sophisticated space robots, to the military flying robots, to the lawn mower robots at our back yard. Mobile robotics is based on many engineering and science disciplines, from mechanical, electrical and electronics engineering to computer, cognitive and social sciences (Siegwart & Nourbakhsh, 2004). A mobile robot is an autonomous or remotely operated programmable mobile machine that is capable of moving in a specific environment. Mobile robots use sensors to perceive their environment and make decisions based on the information gained from the sensors.

The autonomous nature of mobile robots is giving them an important part in our society. Mobile robots are everywhere, from military application to domestic applications. The first mobile robots as we know them today were developed during World War II by the Germans and they were the V1 and V2 flying bombs. In the 1950s W. Grey Walter developed Elmer and Elsie, two autonomous robots that were designed to explore their environment. Elmer and Elsie were able to move towards the light using light sensors, thus avoiding obstacles on their way. The evolution of mobile robots continued and in the 1970s Johns Hopkins University develops the "Beast". The Beast used an ultrasound sensor to move around. During the same period the Stanford Cart line follower was developed by Stanford University. It was a mobile robot that was able to follow a white line, using a simple vision system. The processing was done off-board by a large mainframe. The most known mobile robot of the time was developed by the Stanford Research Institute and it was called Shakey. Shakey was the first mobile robot to be controlled by vision. It was able to recognize an object using vision, find its way to the object. Shakey, shown in Figure 1, had a camera, a rangefinder, bump sensors and a radio link.

These robots had limitations due to the lack of processing power and the size of computers, and thus industrial robotics was still dominating the market and research. Industrial manipulators are attached to an off-board computer (controller) for their processing requirements and thus do not require an onboard computer for processing. Unlike industrial robots, mobile robots operate in dynamic and unknown environments and thus require many sensors (i.e. vision, sonar, laser, etc.) and therefore more processing power. Another important requirement of mobile robots is that their processing must be done onboard the moving robot and cannot be done off-board. The computer technology of the time was too bulky and too slow to meet the requirements of mobile robots. Also, sensor technology had to advance further before it could be used reliably on mobile robots.

In the last twenty years we saw a revolution in computer technology. Computers got smaller, a lot faster and less expensive. This met the requirements of mobile robots and as a result we saw an explosion of research and development activities in mobile robotics. Mobile robots are increasingly becoming important in advanced applications for the home, military, industry, space and many others. The mobile robot industry has grown enormously and it is developing mobile robots for all imaginable applications. The vast number of mobile robot applications has forced a natural subdivision of the field based on their working environment: land or surface robots, aquatic/underwater robots, aerial robots and space robots. Land or surface robots are subdivided based on their locomotion: Legged robots, wheeled robots and track robots. Legged robots can be classified as two legged (i.e. humanoids) robots and animal-like robots that can have anywhere from four legs to as many as the application and the imagination of the developer requires.

Fig. 1. Shakey the Robot in its display case at the Computer History Museum

The revolution of mobile robotics has increased the need for more mobile robotics engineers for manufacturing, research, development and education. And this in turn has significantly changed the nature of engineering and science education at all levels, from K-12 to graduate school. Most schools and universities have integrated or are integrating robotics courses into their curriculums. Mobile robotics are widely accepted as a multidisciplinary approach to combine and create knowledge in various fields as mechanical engineering, electrical engineering, control, computer science, communications, and even psychology or biology in some cases.
The majority of robotics research is focusing on mobile robotics from surface robots, humanoids, aerial robots, underwater robots, and many more. The development of several less expensive mobile robotic platforms (i.e. VEX Robotics Design System (VEX Robotics Design System, 2011), LEGO Mindstorms (LEGO Education, 2011), Engino Robotics (Engino international website – play to invent, 2011), Fischertechnik (Fischertechnik GmbH, 2011), etc.),

the development of countless of robotics software tools and programming languages (i.e. Microsoft Robotics Studio (Microsoft Robotics Developer Studio, 2011), RoboLab (Welcome to the RoboLab, 2011), ROBOTC (ROBOTC.net, 2011)) and the development of many robotic simulators have made robotics more accessible to more educators, students and robot enthusiasts at all levels. This and the fact that using mobile robots in education is an appealing way of promoting research and development in robotics, science and technology, has triggered a revolution of mobile robotics education, research and development. Now educators, researchers, and robot enthusiasts are pursuing innovative robotic, electronic, and advanced mobile programming projects in a variety of different fields.

This chapter provides an overview on mobile robotics education and research. Rather than attempting to cover the wide area of this subject exhaustively, it highlights some key concepts of robotics education at the K-12 and the university levels. It also presents several robotic platforms that can be used in education and research. Various mobile robotic competitions for K-12 and university students will also be presented.

2. Education and research

Since the late 1980s, when robotics was first introduced into the classroom, mobile robotics is used in education at all levels and for various subjects (Malec, 2001). Mobile robotic technology is introduced at the school level as a novelty item and teaching tool. Even though robotics as a field is recognized as a separate educational discipline, it is usually incorporated within the computer science and engineering departments. Robotics courses are becoming core curriculum courses within these departments at most universities. Currently only a small number of universities have pure robotics departments. As the demand for specialized robotics engineers becomes greater, more universities will start to offer robotics degrees and have robotics departments.

It is a known fact that most students, regardless of age and educational background /interests, consider working with robots to be “fun” and “interesting”. Mobile robotics is used in education in many ways, but generally there are two approaches on how mobile robots are used (Malec, 2001). The first, and most obvious, approach is using robots to teach courses that are directly related to robotics. These courses are usually introductory robotics courses and teach the basic concepts of mobile robotics. These courses are usually divided into lectures and laboratory sessions. At the lecture sessions students learn concepts such as kinematics, perception, localization, map building and navigation. At the laboratory sessions, students experiment on real or simulated robots. Experiments are done on robotics concepts and most times students are required to use concepts they learned in other courses, such as control and programming. This method of using/teaching robots in education is primarily used at the university level and very few times we see it at the high-school level. The second approach is to use mobile robots as a tool to teach other subjects in engineering, science and even non-related fields such as biology and psychology. Since students enjoy working with robots, learning becomes more interesting. This allows robotics to be incorporated into various disciplines and departments. This method is primarily used at the K-12 levels of education to teach technology related courses. It can easily be used at the first year of university level to teach courses such as programming and control. Mobile robots can also be used outside the science and engineering fields to teach biology students for example about leg locomotion or to create studies for psychology students on how mobile robotics is affecting our personal life.

The majority of the mobile robotics activities are offered at the university level, but over the last few years we have seen many robotics courses, competitions and other robotics activities offered at the K-12 level of education as well. Many K-12 school systems are starting to teach young people using robots. At the high-school level (ages 16 to 18) robotics is often used to teach programming courses. The most commonly used robots at this level are the Lego Mindstorms NXT and the VEX Robotics Design Systems. The nature of mobile robotics allows it to be an effective tool in teaching technology courses to children at the primary and early secondary levels (from the ages of 6 to 15). Companies such as Engino Toy Systems and LEGO have started developing robotics packages that can be used to teach basic physics and technology concepts to young children, even from the age of 6. By introducing robotics at the K-12 level of education, students may be better prepared for the university and more students will be interested in robotics as a field of study.

The results of the success of robotics in the education of young children has triggered many successful local, national and international robotics competitions (i.e. FIRST LEGO League (USFIRST.org – Welcome to FIRST, 2011), RoboCupJunior (RoboCupJunior, 2011)), many robotics workshops and summer camps for students of all levels. These activities have generated more momentum in robotics education and research and already many educational systems are starting to offer robotics education even at the early stages of K-12 education. Companies such as Engino Robotics (Engino international website – play to invent, 2011) and Lego Education WeDo (Lego Education WeDo, 2011) are developing robotic platforms to be used specifically at the primary school level (ages 6-12). This momentum must be carried over to the university level but in most cases it is not. University students must wait until their third or fourth year before they can take their first robotics course.

Most universities only offer an introductory course in robotics and only a few offer more advanced courses. Most advanced robotics courses are offered at the graduate level. Where advanced courses are offered, specific concepts such as vision, advanced navigation, map-building and sensor fusion are targeted. At the undergraduate level, usually students only go beyond the introductory courses only in the form of final year projects or other projects. In many cases, robotics interested students form robotics groups in order to exchange information, to participate in robotics competitions or to just build a mobile robot. By offering robotics courses early at the undergraduate level will create a natural continuation to the K-12 robotics education. By introducing more advanced mobile robotics courses at the undergraduate level, we will have better prepared students for the graduate level, make more research progress in the long run and have more prepared workforce for the robotics industry as well.

3. Teaching robotics at the K-12 level

It has been proven that hands-on education provides better motivation for learning new material. Abstract knowledge is more difficult to comprehend and sometimes not interesting enough for most students. By providing experiments and real-world situations, students become more interested and they learn new topics much easier.

There is a lack of student interest in science, technology, engineering, and math (STEM) topics and increasing attention has been paid to developing innovative tools for improved teaching of STEM. For this reason alone, hands-on education has been imposed on today's K-12 teachers. Mobile robotics has been shown to be a superb tool for hands-on learning, not only of robotics itself, but of general topics in STEM as well (van Lith, 2007). Mobile robotics is a great way to get kids excited about STEM topics. Students at this level do not need to have a considerable understanding about how robots work. The approach used at this level is to experiment, learn and play. It is also highly effective in developing teamwork and self-confidence. Even children with no interest in technology and sciences still consider robots interesting. Utilizing this interest, robots are used to teach children about robots or using robots as a tool to teach STEM topics. The study of robotics, by its very nature, captures all four legs of STEM very well while creating classroom environments where both knowledge and skill development can flourish without having to compromise one for the other.

But getting students interested in science and other subjects is only one part of the equation, as we must also prepare them for logical thinking and problem solving. At this level it is beneficial to start solving logical problems as the brain is forming in order to develop the required neural plasticity that can be employed over a lifetime of logical thinking and problem solving (Matson et al., 2003). In order to succeed in this, the right tools have to be selected. Choosing the right tools is difficult when competing with high-tech computer games, electronic gadgets and other toys that children are using today. Children today need more stimulation than ever before in human education. Young people are very good at using gadgets and electronic toys, but not many of them are interested in how these devices work or are built (Malec, 2001). We need to stimulate their interest in technology and science in order to make them try to understand the functionality of the devices they use. If they understand, then they will want to develop. Thus it is critical to provide engaging hands-on education to all children as early as possible in order to open their minds to the technology career choices in the STEM areas.

It has been shown that no age is too young for being engaged by robots. Toddlers express deep interest in active machines and toys; robots motivate even children with special social and cognitive needs (Chu et al., 2005). Increasingly, high schools across the world are providing elective robotics courses as well as after-school programs. Gradually, middle schools are starting to get involved, as well. Slowly, even children at the elementary schools are being exposed to robotics (Lego Education WeDo, 2011; Engino international website – play to invent, 2011). There are also many robotics competitions that were designed specifically for these age groups; some of the most visible are FIRST (FIRST, 2011) LEGO Mindstorms (LEGO Education, 2011), VEX Robotics Competition (Competition - VEX Robotics, 2011) and RoboCupJunior (RoboCupJunior, 2011). These competitions increase the interest of students since they add the ingredient of competition.

Generally there is a lack of age appropriate robotics teaching materials for the K-12 level. Normally due to lack of financial resources, schools do not have enough or up-to-date equipment in order to use robotics successfully. Also, because of the broad range of backgrounds of K-12 educators who teach robotics and the lack of appropriate lesson plans, it is critical that ready educational materials be provided in order to teach robotics successfully. There is a lack of available robotics textbooks at this level of education as well. For these reasons, many universities are directly working with school systems to develop robotic material, robotic platforms and appropriate lesson plans in order to aid teachers overcome these problems. Universities must become more involved with K-12 schools and offer activities such as competitions, summer camps, lectures and workshops to students and teachers. K-12 teachers have to be properly educated and trained to use robots in their classrooms.

There are two general categories of mobile robots that are used for education: do-it-yourself (DIY) kits and prebuilt robots. Prebuilt robots are generally more expensive and are only found in university labs, industry and the military. The least expensive prebuild robot cost about 3.000 Euro. Do-it-yourself mobile robots are less expensive and normally cost less than 1.000 Euro. There are many DIY robotic kits that are ideal for K12 education, such as Lego Mindstorms NXT, VEX Robotics Design System and Engino Toy Systems.

Generally students are required to construct and then program the robots. Normally the construction is done by using specific instructions and prepackaged robotic parts, such as LEGO or Engino Toy Systems parts. Most DIY kits are equipped with simple graphical user interfaces (GUI), such as RoboLab (Welcome to the RoboLab, 2011), for students to program the robots. The programming capabilities of these GUIs are limited and are primarily used by students up the middle school (grade 8) level. Students at the high-school level (grades 9 to 12) require more control over their robots, and they often use more advanced programming tools. They use high level languages such as ROBOTC (ROBOTC.net, 2011) or more advanced visual programming languages (VPL) such as Microsoft Robotics Studio (Microsoft Robotics Developer Studio, 2011). Many more high level programming languages and visual programming languages are constantly being developed and this will give students many more options for programming.

Using mobile robotic simulators is another way mobile robotics can be used in education. The goal of simulators at this level is to provide a complete learning experience without the need to have the actual robot hardware. This eliminates the cost of purchasing enough robots to satisfy the needs of all students, since usually one robot is needed per 3-4 students. Simulators are generally less expensive, can be used by all students simultaneously and do not have any hardware costs since they can normally run on existing school computers. In addition to this, the animation of simulation is ideal for today’s children who are keen in animation and gaming. Mobile robotic simulators allow students to virtually build mobile robots and program the robot to perform similar functions as the real robot would.

A very good mobile robotics simulator is the RobotC Virtual Worlds by Carnegie Mellon Robotics Academy (Computer Science Social Network, 2011). It allows students to program simulated Lego NXT and VEX robots using the RobotC programing language. The program offers four mobile robotic challenges: Labyrinth Challenge, Maze Challenge, Race Track Challenge and the Gripper Challenge. Students can also venture on to a simulated extraterrestrial planet environment where they can explore different areas such as the Astronaut Camp and the Container Yard.

In order to have success in robotics education, children from the early stages of K-12 education it would be good for them to be exposed to robotics. Elementary school children (grades 1 to 6) may play and program simple robots. Companies such as Engino Toy Systems and Lego Education WeDo are developing robotic platforms that can be used at the elementary school systems. In the early secondary education (grades 7 to 9) children may build simple robots, program them and even participate in local or international robotic competitions. High school students (grades 10 to 12) may design more complex mobile robots, program them using high level languages and compete in competitions to design robots. Generally by introducing robotics at this younger age group, we will have better prepared students for the university and graduate levels.

3.1 Mobile robotic platforms for K-12 education

Most K-12 educational mobile robots come in the form of kits. Most kits contain building blocks, cables and sensors. They normally come equipped with their own programming interface but sometimes we see third party companies developing software for programming these kits. Older students sometimes prefer using high-level languages to program since it allows them to have more control over the robots and to accomplish more complex functions. The complexity of the kids depends on the age group they are targeting. Some of the most commonly used mobile robot platforms are described here. It is impossible to separate these platforms into age-group categories, since most of them are used by all K-12 groups. Some of these kits are so advanced that are even used at the university level. There are many other available educational mobile robots and the list is growing fast, but it is not possible to list and describe all of them here. The list here is only a selected list based on availability, innovation and usage.

3.1.1 Lego Mindstorms NXT

Lego Mindstorms is a line of programmable robotics/construction toys, manufactured by the Lego Group (LEGO Education, 2011). It was first introduced in 1998 and it was called Robotics Invention System (RIS). The next generation was released in 2006 as Lego Mindstorms NXT (Figure 2). The newest version, released on August 5, 2009, is known as Lego Mindstorms NXT 2.0. Lego Mindstorms is primarily used in secondary education but most universities also use the Lego Mindstorms NXT for their introductory courses in mobile robotics or for projects.

Fig. 2. Lego Mindstorms NXT Controller with sensors and a sample mobile robot

Lego Mindstorms NXT is equipped with three servo motors, a light sensor, a sound sensor, an ultrasound sensor and a touch sensor. The NXT 2.0 has two touch sensors, a light, sound and distance sensors, and support for four sensors without using a sensor multiplexor.

The main component in the Lego Mindstorms kit is a brick-shaped computer called the NXT Intelligent Brick. It can take input from up to four sensors and control up to three motors. The brick has a 100x64 pixel monochrome LCD display and four buttons that can be used to navigate a user interface using menus. It also has a speaker that can play sound files. It allows USB and Bluetooth connections to a computer.

Lego Mindstorms NXT comes with the Robolab (Welcome to the RoboLab, 2011) graphical user interface (GUI) programming software, developed at Tufts University using the National Instruments LabVIEW (NI LabVIEW, 2011) as an engine. With Robolab, students use flowchart like "blocks" to design their program. Students that need to write more advanced programs sometimes prefer to use third party firmware and/or high-level programming languages, including some of the most popular ones used by professionals in the embedded systems industry, like Java, C and C# (i.e. ROBOTC). The programs are downloaded from the computer onto the NXT Brick using the USB port or wirelessly using the Bluetooth connection. Programs can also be run on the computer and wirelessly through Bluetooth can control the NXT brick.

Some of the programming languages that are used to program NXT Brick are:

- NXT-G: Is the programming software that comes bundled with the NXT. This software is suitable for basic programming, such as driving motors, incorporating sensor inputs, doing calculations, and learning simplified programming structures and flow control.
- C# with Microsoft Robotics Developer Studio: Uses the free tools Visual Studio Express and the Robotics Developer Studio and allows programming using the C# language.
- Next Byte Codes (NBC): Is a simple open source language with an assembly language syntax that can be used to program the NXT brick.
- Not eXactly C (NXC): Is a high level open-source language, similar to C. NXC is basically NQC (Not Quite C) for the NXT. It is one of the most widely used third-party programming languages for the NXT.
- ROBOTC: Developed by the Carnegie Mellon Robotic's Academy. ROBOTC runs a very optimized firmware, which allows the NXT to run programs very quickly, and also compresses the files so that you can fit a large amount of programs into your NXT. Like other NXT languages, ROBOTC requires this firmware to be downloaded from the ROBOTC interface in order to run.

Another addition that allows more rigid Lego Mindstorms designs is TETRIX by Pitsco (TETRIX, 2011). The metal building system was designed specifically to work with the LEGO Technic building system through the use of the innovative *Hard Point Connector*. *TETRIX*, combined with custom motor controllers from Hitechnic, enables students to use the power of the Mindstorms technology and incorporate and control powerful DC and servo motors and metal gears. Students can build more versatile and robust robots designed for more sophisticated tasks, all while mastering basic wiring, multi-motor control, and much more.

3.1.2 Fischertechnik ROBO TX training lab

This kit includes the ROBO TX Controller (Figure 3), the construction parts for building mobile robots, the obstacle detector and trail searcher, two encoder motors for exact positioning, one motor XS, one infrared trail sensor and two sensing devices. It also includes the ROBO Pro software for programming. The system can be expanded with the extensive accessories provided by Fischertechnik (Fischertechnik GmbH, 2011).

The ROBO TX Controller is based on a 200Mhz 32-bit processor and is equipped with Bluetooth, eight universal inputs, 8 MB RAM (2 MB flash) and a display. Several ROBO TX Controllers can be coupled together to form more complex systems. The ROBO TX Controller can be purchased separately and can be used in custom designs as well.

This mobile robot kid is suitable for children at the secondary level or university. Everything else is included such as the ROBO interface and ROBO Pro software.

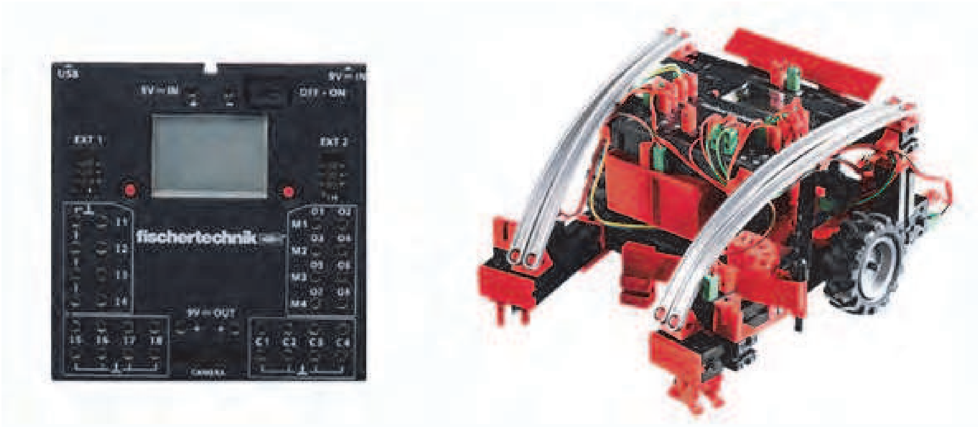

Fig. 3. Fischertechnik ROBO TX Controller and sample mobile robot

3.1.3 VEX robotics design system

The VEX Robotics Design System (VEX Robotics Design System, 2011) is a robotic kit intended to introduce robotics to students. VEX Robotics Design System offers the VEX Classroom Lab Kits that make it easy to bring the VEX Robotics Design System into the classroom. The Classroom Lab Kits include everything you need to design, build, power and operate robots. It comes with four sensors (two bumper sensors and two light switches), four electric motors and a servo motor, and building parts such as wheels and gears. The challenge level for the students can increase by adding expansion kits for advanced sensors, drive systems and pneumatics. Additional sensors (ultrasonic, line tracking, optical shaft encoder, bumper switches, limit switches, and light sensors), wheels (small and large omni-directional wheels, small, medium, and large regulars), tank treads, motors, servos, gears (regular and advanced), chain and sprocket sets, extra transmitters and receivers, programming kit (easyC, ROBOTC, MPLab), extra metal, pneumatics, and rechargeable battery power packs, can all be purchased separately. There are two options on the controllers that can be used with the VEX robotic kits: the basic PIC Microcontroller or the advanced and more powerful CORTEX Microcontroller.

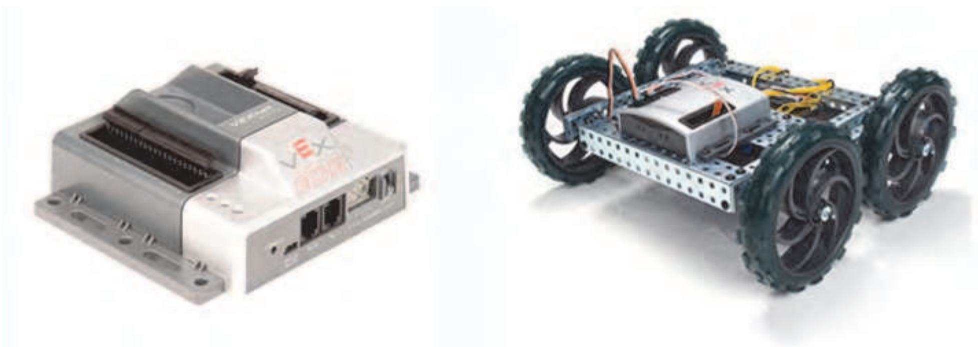

Fig. 4. VEX Robotics Design CORTEX controller and a sample mobile robot

3.1.4 Engino robotics

The engino toy system (Engino international website – play to invent, 2011) was launched in 2007, initially with structural snap fit components and later with gears, pulleys and motors for more complex models (Figure 5). In 2011 the company teamed with Frederic University to develop robotic solutions for primary school students. The robotics module is expected to be officially launched in 2012 and will have 3 modes of operation, making it suitable for both primary and early secondary education (up to grade 8).

The engino controller is based on an ARM 32-bit processor and has four analogue motor outputs, six LED & buzzer outputs, two digital inputs and two analogue inputs. The kit comes equipped with basic building equipment, the controller, motors and basic sensors that include touch, sound, temperature, infrared and light. The controller comes equipped with a USB port that allows it to connect directly to a computer. It can be used to directly control the robots from the computer or to download programs for autonomous functionality.

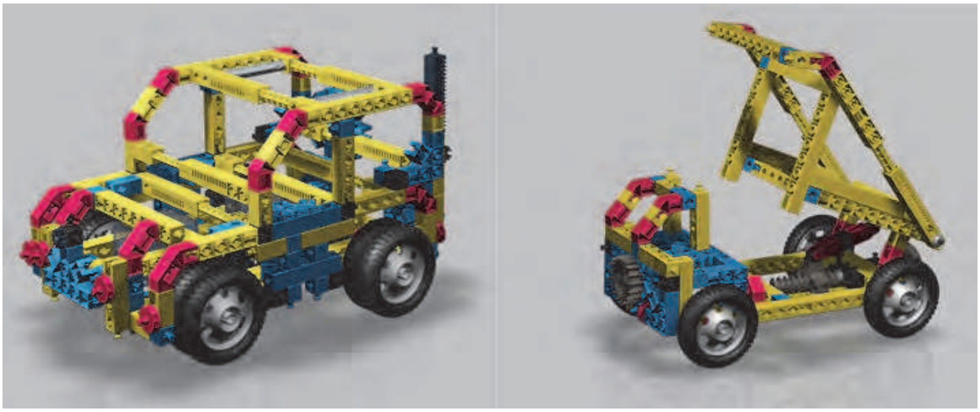

Fig. 5. Engino Robotics sample mobile robots

The module is designed for three levels of programming, basic, intermediate and advanced. The basic level allows manual programming using the existing buttons on the module and allows recording of steps. Younger students (primary education) can be introduced to robotics by recording their steps and functions and then playing them in sequence. It is restricted to two motor outputs and three LED/buzzer outputs. The second level of programming is done on a computer and can fully program the controller. A specialized GUI allows programming the controller using graphical blocks that represent the blocks on the actual system (i.e. motors, sensors, etc). An innovation of the system is that students can create modules of code reusable code that they can use in other programs. The first two levels of programing are suitable for children at the primary education level. The advanced level programming allows students to use a custom made C like high-level language to create more complex programs. This is suitable for students at the secondary education level.

3.1.5 Lego WeDo

The Lego Education WeDo platform is shown in Figure 6. It powered by the LabVIEW software and is ideal for primary school students. Students can build and program their

own robots using the simple, drag-and-drop software. The WeDo is designed to teach simpler concepts to slightly younger kids than other kits. This kit does not allow mobile robot constructions but it is worth mentioning since it is targeting an age group that not many manufacturers target.
By hooking the robots up to your computer via the included USB hub, the WeDo software allows you to program the robots, controlling its actions, sounds and responses. All the programming is drag-and-drop.

Fig. 6. Lego WeDo parts and a robot

3.2 Mobile robotics competitions for K-12 students

Teaching mobile robotics at K-12 level is never a complete task. Students and teachers strengthen their knowledge by participating in mobile robot competitions. The success of robotics in the education of young children has triggered many successful local, national and international robotics competitions such as the FIRST Lego League (USFIRST.org – Welcome to FIRST, 2011), RoboCup@Home (RoboCup@Home, 2011), RoboCup (RoboCup, 2011) and RoboCupJunior (RoboCupJunior, 2011). Only a few international competitions will be briefly mentioned here since trying to name and describe all will be a never-ending task.

3.2.1 VEX robotics competition

VEX robotics competition (Competition - VEX Robotics, 2011) comes at two levels: VEX Robotics Classroom Competition and VEX Robotics Competition (Figure 7). VEX Robotics Classroom Competition is specifically tailored to bring the magic of robotics competition into the classroom. Robotics is an engaging way to integrate all facets of STEM education into the classroom and head-to-head competition is a natural way to capture students' attention. During the excitement that comes with building and competing with their robots, students will be having too much fun to realize they're learning important STEM concepts and life skills. A single teacher can easily implement all aspects of this program as part of their daily classroom activities.
The VEX Robotics Competition is the largest and fastest growing middle and high school robotics program globally with more than 3,500 teams from 20 countries playing in over 250 tournaments worldwide. Local VEX Robotics Competition events are being held in many

different cities throughout the world. In addition to just having a great time and building amazing robots, through their participation in the VEX Robotics Competition and their work within their team, students will learn many academic and life skills.

Fig. 7. VEX robotics competition

3.2.2 FIRST LEGO league and junior FIRST LEGO league

The FIRST LEGO League (also known by the acronym FLL) is an international competition organized by FIRST for primary and middle school students (ages 9–14 in the USA and Canada, 9–16 elsewhere). It is an annual competition and each year a new challenge is announced that focuses on a different real-world topic related to the sciences. Each challenge within the competition then revolves around that theme. The robotics part of the competition revolves around designing and programming LEGO Robots to complete tasks. Students work out solutions to the various problems they are given and then meet for regional tournaments to share their knowledge, compare ideas, and display their robots. The Junior FIRST LEGO League is a scaled-down robotics program for children of ages 6–9.

3.2.3 RoboCupJunior

RoboCupJunior started in 1998 with a demonstration held at the RoboCup international competition held in Paris, France. RoboCup Junior is closely related to the RoboCup competition. RoboCup is an international robotics competition that aims to develop autonomous football (soccer) robots with the intention of promoting research and education in the field of artificial intelligence. Robot cup is described in section *Mobile Robot Competitions for University Students*.

The programming and engineering-influenced competition introduces the aims and goals of the RoboCupJunior project to the primary and secondary school aged level (typically people under the 18). RoboCupJunior is an educational initiative to promote knowledge and skills in programming, hardware engineering, and the world of 3D through robotics for young minds. It aims to fuse real and virtual robotic technologies towards bridging two prominent areas of the future namely, Interactive Digital Media and Robotics. Those involved create and build robots in a variety of different challenges, and compete against other teams. RobotCupJunior is divided into four challenges: Soccer challenge, Dance challenge, Rescue challenge and CoSpace challenge (Figure 8) (van Lith, 2007).

The Soccer challenge is a competition for youth to design, program and strategize autonomous soccer-playing robots. At the Dance challenge, students create dancing robots which, dressed in costumes, move in creative harmony to music. The Rescue challenge is a platform which involves student programming autonomous robots to rescue "victims" in disaster scenarios. And the CoSpace challenges offer an opportunity for RoboCupJunior participants to explore robotics technology, digital media, and CoSpace concept. It also provides a platform for young minds who are keen in animation and gaming into the world of robotics. It offers an opportunity for junior participants to explore the robotics programming and AI strategies with Simulation based competitions. It comprises of two sub-leagues, namely CoSpace Adventure Challenge and CoSpace Dance Challenge.

Fig. 8. RoboCup Rescue and Soccer challenges

4. Robotics at the university level

Mobile robotics is a compelling subject for engineering and computer science undergraduates, but unfortunately most universities do not offer them at the introductory level. Most computer science and engineering departments do offer an introductory course in classical (industrial) robotics but not mobile robotics. These courses generally concentrate on the introduction to industrial robotics and in most cases they incorporate one chapter on mobile robotics. This chapter normally gives a general introduction to mobile robotics concepts and not much more. Mobile robotics courses are usually left as directed studies or are offered only at the graduate level.

Another issue is the fact that robotic courses are not offered at the first year of university education; they are normally offered at the third or fourth year. This creates a problem because it gives no continuation with the robotics education that students are getting in high school. One argument might be that mobile robotic courses require extensive knowledge of electronics, engineering and control. This is true, but it does not mean that the first year university courses must be so involved. The first year mobile robotics course can be a mobile robotic applications course. Another way to introduce mobile robots in the first year of university education is to use mobile robots with other courses such as programing, control and engineering courses in order to offer experimentation of the materials learned. Students learn more when they apply what they learn in lectures to real world applications such as robotics. More advanced mobile robotic topics can be covered with a second or third year course in mobile robotics.

It is only recently that we see many universities start to offer mobile robotics at the undergraduate level. At K-12 education students are normally concentrating on mobile robotics and not industrial robots since mobile robots are more interesting and more fun for students. Therefore, offering introductory mobile robotics courses at the undergraduate level will be a natural continuation of what students were doing in high-school. At this level robots such as the Lego Mindstorms or the VEX Robotics Design System can be used.

In order to have successful graduate students and develop more research at the undergraduate and graduate levels in mobile robotics, more advanced courses have to be offered. There is a need for a pure mobile robotic course that covers the basic concepts of mobile robotics such as kinematics, perception, localization, map building and navigation. Universities that offer robotics degrees and have robotics departments, more specialized courses can be offered to include topics such as vision, behavior coordination, robot learning, swarm robotics, humanoid robotics etc. at the undergraduate level. Beyond this, faculty may offer directed studies and projects (i.e. final year projects or group projects) to students interested in mobile robotics. This will prepare students for industry work and graduate level work.

Universities normally do not have the same problems as K-12 education. There are normally more resources available either from funding agencies, university funds or research projects. Also there is no need to have many robotic systems since there are fewer students using them compared to K-12 schools. At this level, students can also use simulators such as Microsoft Robotics Developer Studio and others. There are definitely enough teaching materials, textbooks, equipment and simulators that can successfully support mobile robotics courses. There are several excellent textbooks such as AI Robotics by Robin Murphy (Murphy, 2000), Computational Principles of Mobile Robotics by Dudek and M. Jenkin (Dudek & Jenkin, 2011), Introduction to Autonomous Mobile Robots by Roland Siegwart and Illah Nourbakhsh (Siegwart & Nourbakhsh, 2004), etc.

Students must grain most of their mobile robotics education at the university level. At the graduate level, robotics courses must be in the form of research, projects and theses. At this level more research must be done.

4.1 Mobile robotic platforms for the university level

There are many mobile robots available at the university level. A few selected ones will be presented and described in this section. The robots will be described in terms of hardware, capabilities, control and applications. The peripherals that can be used for each robot will also be briefly described, if possible. An effort will be made to describe the possible applications for each of these robots.

4.1.1 Lego Mindstorms NXT and Fischertechnik ROBO TX

The processing power and programming flexibilities that these systems offer make them ideal for University introductory courses. Many universities are using these robots very successfully. These systems were described earlier in the *Mobile robotic platforms for K-12 education* section thus the explanation part will be omitted.

These robotic kits are primarily used at the introductory level to teach the basic concepts and principles of perception, localization, map building and path planning and navigation. We often find these type of mobile robots used for projects and/or to develop prototype ideas. Programming at this level is done using high-level languages such as C# with Microsoft Robotics Developer Studio, NBC, ROBOTC or other high-level languages.

4.1.2 VEX robotics design system

VEX robotics was described earlier in section *Mobile robotic platforms for K-12 education*. Many universities are using VEX robotics because of the rigid design, powerful processor and programming flexibility. This kit, like the Mindstorms kit, is primarily used for introductory courses, projects and prototyping.

4.1.3 iRobot create

The Create robot from iRobot (iRobot: Education & Research, 2011) is intended for educational purposes. This robot is based on the iRobot Roomba vacuum cleaner. In place of the vacuum hardware of the Roomba, the Create includes a cargo bay which houses a 25 pin port that can be used for digital and analog input and output. The Create also possesses a serial port through which sensor data can be read and motor commands can be issued using the iRobot Roomba Open Interface protocol. The platform accepts virtually all accessories designed for iRobot's domestic robots and can also be programmed with the addition of a small "command module" (a microcontroller with a USB connector and four DE-9 expansion ports).

The controller of the iRobot is limited in processing power and thus many choose to utilize an external computer in controlling the Create robot. Since the built-in serial port supports the transmission of sensor data and can receive actuation commands, any embedded computer that supports serial communication can be used as the control computer. Popular choices include the gumstix (Gumstix small open source hardware, 2011) line of computers. In many cases laptop computers are used to control the Create through the serial connection.

The Create is supported both in hardware and in simulation by Microsoft Robotics Developer Studio (RDS). An example of an RDS simulation that contains the Create is shown in Figure 10. The Create is the platform used for Sumo robot competitions. The iRobot Command Module for the Create is not required for RDS and is not used.

Fig. 9. iRobot Create

Fig. 10. iRobot Create in Microsoft Robotics Developer Studio Simulation

4.1.4 K-Team SA mobile robots

K-Team (K-Team Corporation, 2011) is a Swiss company that develops, manufactures and markets high quality mobile robots for use in advanced education and research. The Khepera III and Koala II (Figure 10) are found in many university laboratories that specialize in robotics education and research. KoreBot II is the standard controller for the Khepera II and the Koala II. The KoreBot II is a single board controller used for custom robotics developments.

The Khepera III is a miniature mobile robot that has features that can match the performances of much bigger robots. It has upgradable embedded computing power using the KoreBot system, multiple sensor arrays for both long range and short range object detection, swappable battery pack system for optimal autonomy, and exceptional differential drive odometry. Khepera III is able to move on a tabletop but it is also designed to move on rough floor surfaces and carpets.

Fig. 11. K-Team SA Koala II and Khepera III

The Khepera III architecture provides exceptional modularity. The robot base can be used with or without a KoreBot II board. Using the KoreBot II, it features a standard embedded Linux Operating System for quick and easy autonomous application development. Without

the KoreBot II, the robot can be remotely operated. It is easily interfaced with any Personal Computer.
The robot includes an array of nine infrared sensors for obstacle detection as well as five ultrasonic sensors for long range object detection. An optional front pair of ground Infrared Sensors is available for line following and table edge detection. Through the KoreBot II, the robot is also able to host standard Compact Flash extension cards, supporting WiFi, Bluetooth, extra storage space, and many others.
Koala is a mid-size robot designed for real-world applications. It is bigger than Khepera, more powerful, and capable of carrying larger accessories. Koala has the functionality necessary for use in practical applications.
In addition to these new features, Koala retains a shape and structure similar to Khepera, such that experiments performed on Khepera can be migrated to the Koala. The BIOS of both robots is compatible, permitting programs written for one robot to be easily adapted and recompiled for the other.
Programming of the robots can be done by standard cross-C language to more sophisticated tools like LabView, MATLAB (MATLAB - The Language OF Technical Computing, 2011) or SysQuake (Calerga – Sysquake, 2011). In general any programming environment capable of communicating over a serial port can also be used to program these robots. KoreBot II GNU (The GNU Operating System, 2011) C/C++ cross-compiler provides a powerful standard tool for complex code compilation and conditional build. It also supports all the standard C library functions and almost all the other Posix libraries.
The K-team robots are commonly used for experiments and research is Navigation, Artificial Intelligence, Multi-Agents System, Control, Collective Behavior and Real-Time Programming, among others.

4.1.5 Adept MobileRobots

Adept MobileRobots (Intelligent Mobile Robotic Platforms, 2011) offers an array of mobile robots; the Seekur Jr, the GuiaBot and the PowerBot. The most frequently used and most popular research mobile robot is the Pioneer 3DX (P3DX). It is an advanced research robot that is controlled by a computer (PC) and has a large range of sensors (including an optional laser range finder), and communicates via WiFi. The Pioneer's versatility, reliability and durability have made it the reference platform for robotics research. Unlike hobby and kit robots, Pioneer is fully programmable.
The base Pioneer 3DX (Figure 13) platform arrives fully assembled with motors with 500-tick encoders, 19cm wheels, tough aluminum body, 8 forward-facing ultrasonic (sonar) sensors, 8 optional real-facing sonar, 1, 2 or 3 hot-swappable batteries, and a complete software development kit. One of the innovations of Pioneer is that it does not have an on board controller. The robot can be controlled either by an optional internal computer (PC) or an external laptop. The base Pioneer 3DX platform can reach speeds of 1.6 meters per second and carry a payload of up to 23 kg. With the optional Laser Mapping & Navigation System and MobileEyes, pioneer can map buildings and constantly update its position within a few cm while traveling within mapped areas. With the appropriate optional accessories, the robot can be remotely viewed, speak and play and hear audio.
Since it is controlled by a computer, it can be programmed in any programming language that the user selects. I addition to this, the P3DX is supported both in hardware and in simulation by Microsoft Robotics Developer Studio. The Pioneer 3 DX is an all-purpose

base, used for research and applications involving mapping, teleoperation, localization, monitoring, reconnaissance, vision, manipulation, autonomous navigation and multi-robot cooperation and other behaviors.

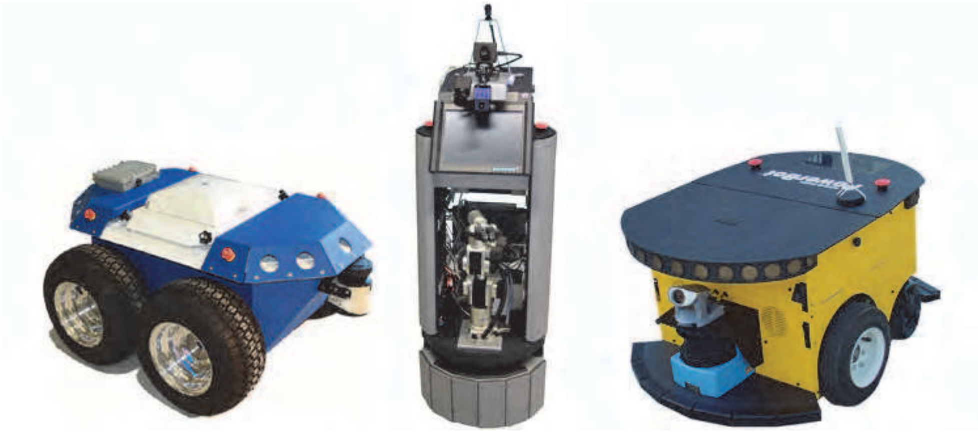

Fig. 12. The Seekur Jr, GuiaBot and PowerBot from Adept MobileRobots

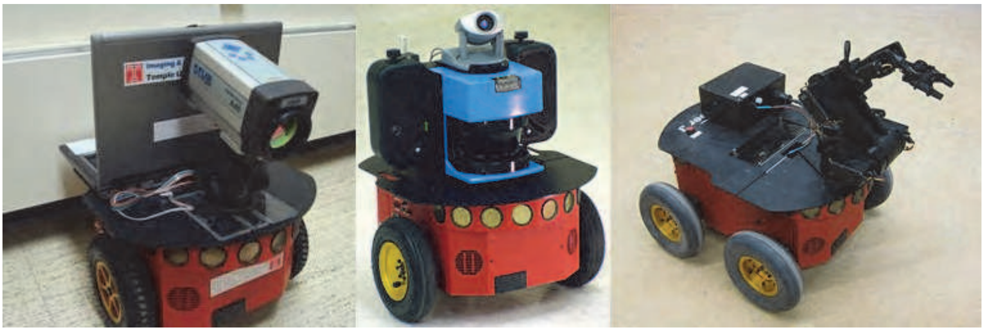

Fig. 13. Adept MobileRobots Pioneer 3DX

4.2 Mobile robot competitions for university students

Robotic competitions attempt to foster several research areas by providing a standard problem where wide range of technologies can be integrated and examined, as well as used for integrated project-oriented education. Additionally, mobile robotic competitions create media interest and this may even generate additional funds from external sources. Normally the work to conceive, build and program the robots is integrated in final graduation projects, extracurricular activities or post-graduation activities. Students are very motivated, because they can integrate most of the knowledge acquired during their courses. Preparing for mobile robot competitions involves interdepartmental co-operations, sometimes not only of the engineering and science departments.

Mobile Robotic competitions are a very motivating way of fostering research, development and education, mainly in Robotics, but also in Science and Technology in general. Mobile robot contests are recognized by the scientific community as a way for the development of research. The practical solutions students find for their projects on their way to a competition will teach them more skills than a course can. There is a wide variety of competitions for robots of various types. The following examples describe a few of the higher profile events.

4.2.1 RoboCup

RoboCup (RoboCup, 2011) is an international robotics competition founded in 1997. RoboCup chose to use soccer as a central topic of research, aiming at innovations to be applied for socially significant problems and industries. The aim is to develop autonomous football (soccer) robots with the intention of promoting research and education in the field of artificial intelligence. The name *RoboCup* is a contraction of the competition's full name, "Robot Soccer World Cup", but there are many other stages of the competition as well. The ultimate goal of the RoboCup project is by 2050, develop a team of fully autonomous humanoid robots that can win against the human world champion team in soccer.

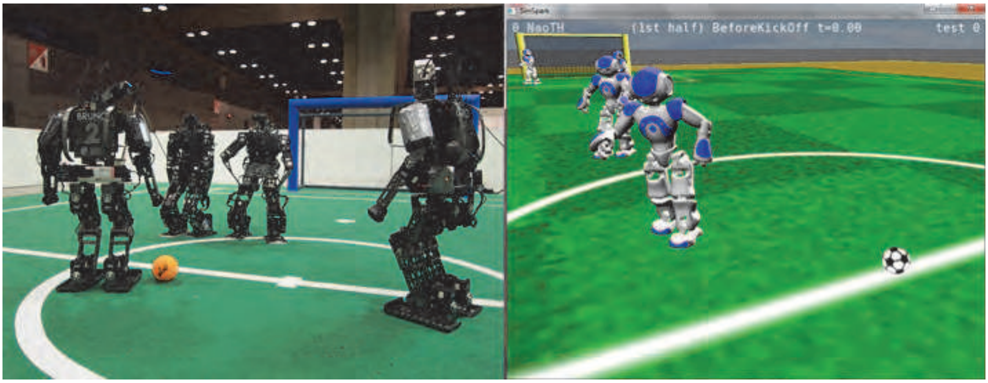

Fig. 14. RoboCup Humanoid and Simulation Competitions

The contest currently has three major competition domains, each with a number of leagues and subleagues: RoboCupSoccer (RoboCupSoccer, 2011), RoboCupRescue (RoboCupRescue, 2011) and RoboCup@Home (RoboCup@Home, 2011). RoboCupSoccer includes a number of sub-competitions: Simulation League, Small Size Robot League, Middle Size Robot League, Standard Platform League and the Humanoid League. Figure 13 shows the humanoid competition and the simulation competition.

The RoboCupRescue Robot League is an international competition for urban search and rescue robots, in which robots compete to find victims in a simulated earthquake environment. RoboCupRescue includes real robot and simulation leagues. RoboCup@Home is a new league inside the RoboCup competitions that focuses on real-world applications and human-machine interaction with autonomous robots. A set of benchmark tests is used to evaluate the robots' abilities and performance in a realistic non-standardized home environment setting. The aim is to foster the development of useful robotic applications that can assist humans in everyday life. The ultimate scenario is the real world itself. To build up the required technologies gradually a basic home environment is provided as a general scenario. In the first years it will consist of a living room and a kitchen but soon it should also involve other areas of daily life, such as a garden/park area, a shop, a street or other public places. Focus lies on the following domains but is not limited to: Human-Robot-Interaction and Cooperation, Navigation and Mapping in dynamic environments, Computer Vision and Object Recognition under natural light conditions, Object Manipulation, Adaptive Behaviors, Behavior Integration, Ambient Intelligence, Standardization and System Integration.

4.2.2 Eurobot

Eurobot (Eurobot, international robotics contest, 2011) is an international amateur robotics contest, created in 1998. It is open to teams of young people, organized either in student projects or in independent clubs. Countries that present more than three teams must organize a national qualification round where only three teams are selected for the final Eurobot competition (Figure 15). These teams could be formed from students as part of their studies or as independent clubs or non-profit organizations. A team must be made up of two or more active participants. Team members may be up to 30 years old, each team may have one supervisor for which this age limit does not apply. The contest aims at interesting the largest public to robotics and at encouraging the group practice of science by youth. The competition includes a conference for the students and the public. Eurobot is an opportunity to unleash technical imagination and exchange ideas, know-how, hints and engineering knowledge around a common challenge.

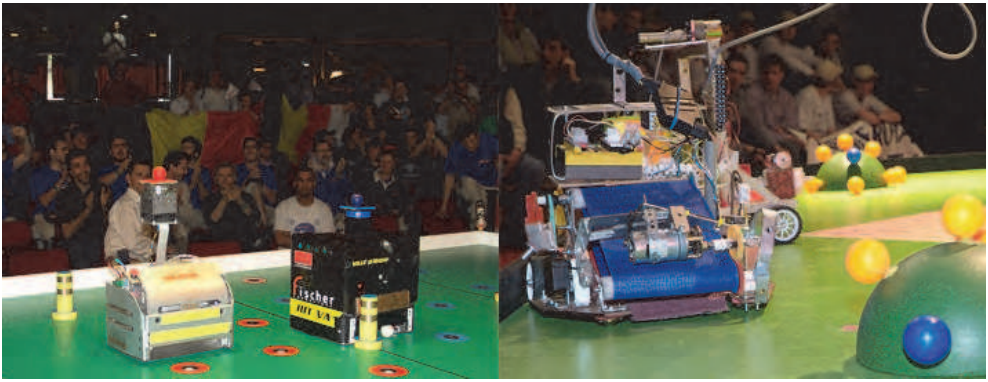

Fig. 15. Eurobot competitions

4.2.3 European Land-Robot trial (ELROB)

ELROB (Elrob-Website, 2011) is a European event, which demonstrates the abilities of unmanned robots. The ELROB is an annual event and alternates between a military and a civilian focus each year (Figure 16). Only teams from Europe are allowed. But teams of both commercial and academic backgrounds are allowed.

ELROB is designed to assess current technology to solve problems at hand, using whatever strategy to achieve it. The scenarios are designed to simulate real world missions, be it military or civilian ones. There are no artificial constraints set to these scenarios to ease the task for the robots like e.g. very visible road markings. This forces the participating teams and systems to fulfill high requirements set by the real world scenarios.

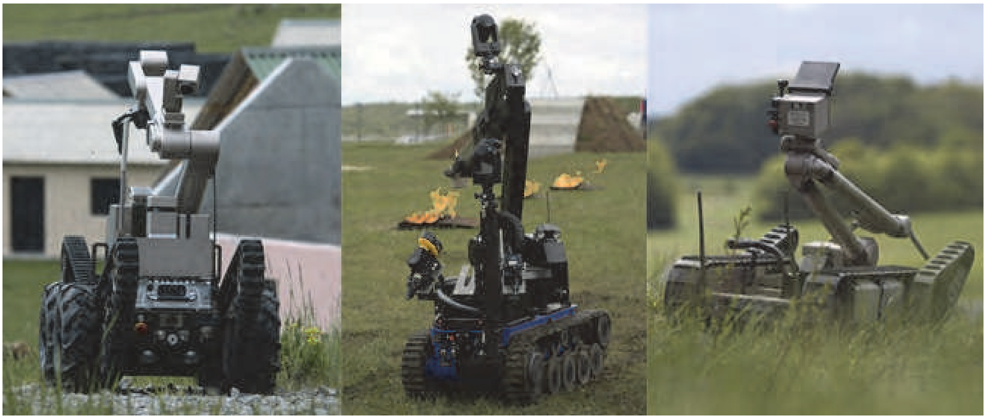

Fig. 16. ELROB military competition robots

5. Conclusion

Mobile robots are becoming part of our everyday life in many forms. The mobile robot industry, other organizations and universities are developing mobile robots for all imaginable applications. Mobile robot research and development are at their highest. There is a need for specialized mobile robotics engineers and scientists.

The mobile robotics momentum that has been created over the last two decades must not stop. More courses and more activities are needed starting from the early K-12 education. This is now possible because of the development of various types of mobile robots and simulators. The existence of various mobile robotics competitions gives extra motivation to students and educators to do more work in mobile robotics.

Teaching with robots from the early stages of K-12 education will better prepare students for high school mobile robotics education and competitions. At the university level, introductory level mobile robotics courses must be offered. More advanced mobile robotics courses must also be offered that specialize in topics such as vision, localization, navigation, etc. At the graduate level, students must concentrate on research and projects. This will create a continuation on mobile robotics education, from K-12 all the way to graduate school, and thus creating better prepared graduate students, developing more research interest and creating skilled graduates for the many jobs that are opening up in the mobile robotics industry.

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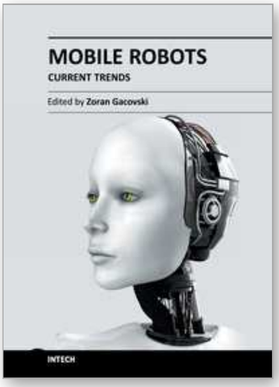

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This book consists of 18 chapters divided in four sections: Robots for Educational Purposes, Health-Care and Medical Robots, Hardware - State of the Art, and Localization and Navigation. In the first section, there are four chapters covering autonomous mobile robot Emmy III, KCLBOT - mobile nonholonomic robot, and general overview of educational mobile robots. In the second section, the following themes are covered: walking support robots, control system for wheelchairs, leg-wheel mechanism as a mobile platform, micro mobile robot for abdominal use, and the influence of the robot size in the psychological treatment. In the third section, there are chapters about I2C bus system, vertical displacement service robots, quadruped robots - kinematics and dynamics model and Epi.q (hybrid) robots. Finally, in the last section, the following topics are covered: skid-steered vehicles, robotic exploration (new place recognition), omnidirectional mobile robots, ball-wheel mobile robots, and planetary wheeled mobile robots.