In Proceedings of the Third International Symposium on Human and Artificial Intelligence Systems: The Dynamic Systems Approach for Embodiment and Sociality, Fukui, Dec 6-7, 2002 (HART2002).

An Edutainment Robotics Survey

Henrik Hautop Lund   Jacob Nielsen

Maersk Mc-Kinney Moller Institute for Production Technology
University of Southern Denmark, Campusvej 55, 5230 Odense M., Denmark

hhl@mip.sdu.dk   raider@mip.sdu.dk
www.adaptronics.dk

Abstract. In this survey, we describe different categories of edutainment robots. We classify these in robots with no interaction, with limited interaction, and extensive interaction possibilities. A non-exhaustive market survey shows that there are numerous edutainment robots in all categories, and psychological considerations suggest that the systems with extensive interaction and construction possibilities may provide advantages, in some cases. In order to explore these categories, we made development for all three categories and describe the experiments briefly.

1 Introduction

The term "edutainment" is a gathering of the words education and entertainment, and has been around for about 10 years. The general concept of edutainment is to make learning fun, based on the philosophy that children learn faster when playing their way to knowledge. Originally the term edutainment was invented with regards to educative computer programs, but the term certainly covers almost every toy that have been around for as long as children have been playing, as playing in itself is an educative act.

Most of the robotic games for children were developed by putting emphasis on an educational approach, in which the children are allowed to learn about technology in Piaget's manner. However, we find that it is not enough just to promote this kind of learning. Suitable tools will have to be available for teachers and children, so we propose user-guided approaches based on adaptive systems techniques. These may include user-guided behaviour-based systems, user-guided evolutionary robotics, user-guided co-evolutionary robotics, and morphological development, e.g. in relation to the HYDRA project (www.hydra-robot.com). The techniques should be applied to allow children to develop their own robot behaviours in a very easy and fast manner. At the same time, the techniques should be so simple that most teachers will have no difficulties in understanding and using them.

However, it should be realized that the autonomous systems approach also might introduce an educational problem. Often, in autonomous systems research, the goal is to achieve fully autonomous robots, both in the development and the behaviour. This is highly desirable from a theoretical point of view and in some fully autonomous systems applications, but sometimes, in other applications, it may turn out to be less desirable. For instance, in entertainment that involves construction, the user would like to be able to direct the development of the system, and in production systems, the worker in a production hall might want to re-configure the robot for flexible production. We try to solve this problem by introducing the user-guided approaches.

When developing educational robotics, it is important to note, that there are significant differences in between the different robots emerging on the market, as mentioned in the small survey below. In some cases, the robots are fully autonomous both in development and behaviour (e.g. Furby) and so give *no* possibility for development by the user, in some cases there are *limited* possibilities for development by the user (e.g. I-Cybie, AIBO), and in other cases there are *extensive* possibilities for development by the user (e.g. LEGO MINDSTORMS, FischerTechnic robot). In the future edutainment robotics work, we will probably concentrate on the latter kind of robotic systems, since we view these systems to best facilitate an educational approach in applications for children (though, initially, we have explored all three kinds in order to create the best possible basis for the future edutainment robotics work).

Robotic tools for entertainment and edutainment

The entertainment/edutainment sector has during the last couple of years tried to introduce AI to children through various more or less intelligent toys. A few of these toys are described in the sections below.

Tamagotchi

The tamagotchi is one of the first interactive pet toys released by the toy-industry. It was released on November 23rd, 1996 by the toy-company Bandai. A picture of a tamagotchi can be seen in Figure 1.1. It consists of a display for showing the little creature and buttons for entertaining it, feeding it, putting it to sleep, playing games, and generally keeping it satisfied. Besides the display, the tamagotchi has a built in beeper to express its state of mind by playing happy tunes or making unsatisfied squeaks.
The Japanese story that are presented to the tamagotchi-owners goes like this: *They are little alien creatures from Planet Tamagotchi, who crash landed on earth, and The Professor and his assistant Mikachu found them. The Professor built them little egg shaped protection cases so they could*

survive on earth, then Mikachu painted some, took them to school and started the Tamagotchi craze...

Figure 1.1: The 1. generation Tamagotchi.

The educative part in this toy is clearly to teach children how to care for and take care of another living creature. The goal of the tamagotchi game is to keep your tamagotchi on Earth for as long as possible, because if it is unhappy it will go back to Planet Tamagotchi. When you first turn on your tamagotchi it is an unhatched egg and after 5 minutes this egg will hatch, and the care taking starts. The little tamagotchi needs a lot of love and attention and depending on how well you treat it, it will develop into one of 6 different characters in the next generation - so it is how well you care for the tamagotchi that will determine which character you get in the final adult stage.
The tamagotchi concept has lately been adopted by web-designers and programmers, and today there are lots of different virtual pets (and plants) available online for children and adults to explore.

The tamagotchi has definitely shown that toys can be made, which are loveable enough to make people spend an enormous amount of time on it and for some develop a kind of mother-child bond that leads to actual sorrow when the creature finally departures back to its planet. All this is done with a simple behavior based kind of AI programmed in to the tamagotchi, and the fact that children (of all ages) are able to actually love such a simple electronic pet actually tells more about the human being than the actual intelligence of the toy. However, its edutainment qualities are unquestionable.

Furby

The Furby (shown in Figure 1.2 is a somewhat more complex and animal-like interactive pet toy compared to the tamagotchi. It was released by the Tiger Electronics company in December 1998.

Figure 1.2: The Furby in one of its many designs.

Like the tamagotchi the Furby has a quite similar introductory history of its own, which has been written to make the creature even more loveable, and it goes, *Furby's come from the clouds. They looked down and saw the Earth. They loved the look of it and decided they wanted to live there with people. So they jumped down from the clouds on to Earth. And went to their new homes.*

The Furby has sensors that react to light, sound, touch and physical orientation (standing or upside down). The infrared sensor, which looks like a third eye, allows Furbys to communicate among themselves, and even transmit colds that result in sneezes! The Furby can also communicate with humans using its "Furbish" language - the toy gradually learns some English words, too - and body language, including winks, ear twitches, and wiggling.
The educational aspect of the Furby is somewhat the same as for the tamagotchi, but the Furby is definitely more robot than the tamagotchi ever was, and it is its sensors and actuators that allows for much more physical interaction. The language furbish is also a language that the user should learn in order to understand the pet toy.

Seen from an AI point-of-view the Furby does not seem impressive. Everything the Furby is "taught" during its life is already pre-programmed and activated by the level of attention and caring it receives. Therefore it can principally not be called intelligent, as it hasn't got the ability to learn anything by itself.

AIBO

The AIBO robot is a robotic pet dog invented by SONY corp. , and the first version (ERS-110) was released in June 1999. AIBO is powered by a RISC-processor utilizing numerous sensors, a color camera and 18 motors to move its extremities. Besides this high tech robotic system the robot features a very sophisticated emotion- and instinct-model, which allows it to have animal-like behavior and reactions, as well as to simulate maturation.

Figure 1.3: Three versions of the SONY AIBO robot dog.

The three versions of the AIBO shown in Figure 1.3 differ both in complexity and costs. The most complex and expensive version is the AIBO ERS-220 (The middle image.), which offers voice recognition of 75 different commands and expresses itself through tonal and body language. Besides that it has more control lights to express its current mood and the ability to communicate with a PC through wireless LAN.

The behaviors of the AIBO are instinct based, which means that the robot is constantly reacting to and learning from the environment around it. Depending on how its owner is fulfilling its instincts for food, sleep, movement, search and love it will decide which emotion it is feeling, be it happiness, sadness, anger, fear, discontent or surprise. AIBO will express its emotions using a combination of its expressive face and tail lights, tones and body language. If communication with the owner or another AIBO goes well, then it may become excited and enter Boost Mode. With this mode its headlight will be raised and illuminated and its movements will become very energetic and it will want to show off. However, as the robot tires it will revert to autonomous mode, becoming withdrawn until it has recovered enough energy to resume normal behavior.

The AIBO robot is accompanied by the AIBO Navigator software, which enables the user to have direct control over the AIBO from his/her PC through e.g. a joystick. In this way it is possible to override the basic instincts of the robot and use it to explore rooms etc. via the onboard camera.

The level of intelligence implemented in the AIBO is far more complex than that of the Furby, and the autonomy gives it the ability to develop its character from its interactions with its environment.

My Real Baby

This toy is an interactive, robotic, artificial intelligent and emotionally responsive baby doll, and it is produced in collaboration between iRobot and Hasbro.

What goes for the technology, this robot toy includes a realistic animated face, voice, and several sensors, that makes the robot detect how it is being held and touched or how it is being moved or how the lightning conditions are. At the bottom of these actuators and sensors lies a sophisticated artificial intelligence system that gives the doll its own set of emotions and drives. In this way the child will experience responsive play, where the doll senses and reacts to many of the ways it is being played with. Currently there are the two versions of My Real Baby, which can be seen in Figure 1.4.

Figure 1.4: The two versions of My Real Baby.

The technology behind the My Real Baby doll is iRobot's Behavior Language Operating System, which is developed by Rodney A. Brooks, director of MIT Artificial Intelligence Laboratory. Using this behavior language, the doll is able to interpret what happens to it using a model of over 15 human-like emotions and levels of emotional intensity. In this way, the doll is able to distinguish if it is being hugged, rocked, fed, burped, bounced etc.

The My Real Baby has been developed in close relations with children, and therefore the behaviors have been implemented trying to mirror the way children would expect the doll to react in certain situations. In this way, the doll is, by the manufacturer, expected to be able to "teach" children (or even adults) how to care for babies, and maybe prepare them for a younger brother or sister.

Paro, Tama and other therapeutic robots

In a quite similar way, Shibata has developed therapeutic robots together with OMRON. Two examples are the seal robot, Paro, and the cat robot, Tama, as shown in figure 1.5. In this line of research and development, it is believed that it is possible to develop emotional creatures, and that both children and elderly people may benefit from taking care of these robots. There is no construction in these robots, but the interaction happens with a robot with predefined behaviour and morphology.

Figure 1.5. The Paro seal robot (left) and the Tama cat robot (right) developed for therapeutic use.

SDR-4X

This name covers a new small SONY prototype biped entertainment robot. This robot has a humanoid shape as can be seen in Figure 6 and it is able keep balance while walking, -even on irregular and tiled surfaces. Furthermore, this robot is able to determine distance to objects with its built in stereo vision and determine direction of sounds due to 8 built in microphones. There are 28 actuators in the SDR-4X, and these are all controlled by the Real-time Integrated Adaptive Control System, which bases the movement on various sensor-inputs gathered in real time.

The SDR-4X has continuous speech recognition, and is able to learn and memorize new words. Besides, it has the ability to recognize individuals by the tone of their voice. Speech synthesis is also implemented, which gives the robot the possibility to express feelings with synchronized emotionally expressive speech and body language.

The robot is also able to detect and recognize up to 10 different human faces (Seen from the front). This allows for the robot to know its owner not only by his/her voice.

Another functionality of this robot is its ability to plan (calculate) walking paths through a room, by using its stereo vision to recognize and avoid objects.

This robot is clearly one of the most sophisticated and complex entertainment/edutainment robots to this date, and it is expected, that the price of one robot will be equal to that of a luxury car. However, as the robot is no higher than approximately 60 centimeters it is not likely to be anything else than an entertainment robot, because it will not be able to handle adult human size things appropriately. E.g. it will not be able to open a standard size door or reach things on a standard size table.

Figure 1.6: The SDR-4X on a surf board.

WonderBorg

This product is made by Bandai co. It is a small compact 6-legged insect-like robot that comes as an assembly kit, with the possibility to alter the shape of the legs and the sensing antennas using different parts from the assembly kit. A picture of the different parts of the kit can be seen in Figure 1.7.

Figure 1.7: The WonderBorg assembly kit.

Besides the actuators for the legs, the WonderBorg set comes with built–in infrared sensors and touch sensors for the antennas.
The WonderBorg has been developed to introduce robotics to children, so that the user experiences both the assembly of the robot and after that the programming, which is based on a behavioral subsumption architecture. The legs of the robot can be bent and different shapes can be explored to find the wanted method of movement.

The built robot can be programmed through an infra-red communication box that is connected to a PC through a serial COM cable. In the accompanying programming language, the user has to line up actions to the right of the icons that are representing the robot sensors. In that way several lines of actions are made which are prioritized so that the top-most action has highest priority.

Figure 1.8: One configuration of an assembled WonderBorg.

Wonderborgs event–driven programming model has proven to be child-friendly and educational through having been used in a children's Insect Robot Contest involving simple mazes and obstacle avoidance races. This was for instance the case at RoboFesta in Yokohama, November 2001, where the WonderBorg was used in the international friendship games.

Also, Bandai developed the BN-1 cat robot, which is less modular than the WonderBorg robot but has a similar programming interface.

Figure 1.9: The BN-1 cat robot.

LEGO Mindstorms

LEGO Mindstorms was launched by LEGO in 1998 as a natural extension of the LEGO company's previous products. The Mindstorms product was developed in cooperation with MIT Media Lab researchers in learning and technology. The LEGO Lab in Aarhus under the direction of H. H. Lund engaged in collaboration with LEGO regarding the development in 1997, after having performed pilot projects with other LEGO robot platforms at the University of Edinburgh in 1996-97.

The LEGO Mindstorms product is a much more interesting toy than the two mentioned in the previous sections, seen from an engineering point-of-view, because it enables children to build their own pet toys or any kind of other imaginable robotic machinery, like the one shown in Figure 1.10, by building actuators and sensors into standard LEGO constructions, connecting them to the computer brick (RCX - shown in Figure 1.5) and programming their own behaviors into the RCX.

The educative part of this toy is to make children able to construct, be creative and collaborate through curiosity, excitement, concentration, pride and joy which are all the primary pathways to learning.

Figure 1.10: A LEGO Mindstorms Robot.

The electronic parts that make up the Mindstorms system are:

RCX - This is the "brain" of the system, which allows for 3 sensory inputs and 3 motor outputs. The brick includes a display and buttons for selecting programs, viewing status of sensors/motors, on-off and run. Besides the RCX includes an IR serial port, through which it is programmed.

Figure 1.5: The LEGO Mindstorms RCX brick.

Motor - A quite powerful motor that is compatible with all of the Technics LEGO through its output axle.

Light Sensor - Able to sense IR light and measure reflection on materials.
Bump Sensor - Reacts to pressure, and can be used for detection of wall-bumping and so forth.
Temperature Sensor - Allows for temperature measurement, although it is somewhat delayed

Later on, more sensors and electronic tools, like e.g. a camera, have appeared in the Mindstorms world through various kits and extension kits. The standard or basic kit is the ROBOTICS INVENTION SYSTEM (RIS).

The software that accompanies the RIS is a very child-friendly visual programming language, where the user can drag the blocks that are wanted onto the previous chosen block. In this way the connection of the different programming blocks create the final program. There are blocks for everything from sensors to structural commands like if-sentences, timers and so on. Having any previous knowledge of programming is not necessary in order to use this programming language. Most things can be learned through help-files and examples.

Fischertechnik

The toy provided by Fischertechnik is somewhat similar to that of LEGO Mindstorms. Arthur Fischer launched the first Fischertechnik toy in 1965. The first sets included only connectable plastic modules, which has now been expanded by actuators, sensors and a central control module, which can be programmed from a PC through a serial port. The basic brick in the Fischertechnik set can be seen in Figure 1.12.

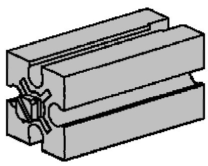


Figure 1.12: One of the basic Fischertechnik bricks.

The Fischertechnik robotic kits contain a great amount of educational aspects, both with respect to programming and especially with respect to the construction of the robots. The kits are, however, difficult to comprehend for small children and especially the wires and connectors are tiny, and difficult to connect and disconnect without breaking them.

Besides the building bricks, the Fischertechnik robotic kit, Mobile Robots contain the central processing unit, two motors, six switches, two light sensors and one light source. The electrical circuits are supplied by a separate battery pack, which is a central unit in all of the constructions that follows this kit.

The programming interface for the Fischertechnik robots is also quite similar to that of LEGO Mindstorms due to the fact that the user can drag graphical representations of functionalities, such as “run motor X for Y seconds” onto a work area and combine these functionalities into sequential and concurrent programs.

Figure 1.13: An industrial Fischertechnik example.

There are a lot of applications for the Fischertechnik product, and the model shown in Figure 1.13 is a Fischertechnik simulation model, which proves this toys versatility by the fact that this model can be used to simulate real industrial machinery and thereby visualize and prove the correctness of a work process before expensive machinery is bought.

K’NEX

K’NEX is another construction kit toy developed by K'NEX Industries, Inc. The idea of this modular toy is somewhat the same as both LEGO and Fischertechnik. However, the shape of the different parts are not the same as either of these toys. K’NEX also call themselves the number one construction toy company in the non-brick category.

The robotic construction set that has been developed from this toy is called CyberK’NEX. This set includes, besides the different building parts, motors, sensors and the control is based on little so-called Cyber Keys, that hold the behavior of the robots built. The Cyber Keys are normally preprogrammed from factory, and cannot be altered, however, a programmable Cyber Key can be bought along with a PC programming set, which allows for the user to develop his/her own behaviors for the robots. An example of a CyberK'NEX robot can be seen in Figure 1.14.

Figure 1.14: The CyberK'NEX Mechtron robot.

The different CyberK'NEX sets allow the user to build a couple of different robots, to which appropriate Cyber Keys are included. So if the user would like to build something from his/her own imagination it is not likely that the included Cyber Keys hold the right set of behaviors. Therefore it is necessary for the user to have the programmable Cyber Key in order to explore own ideas. In this way, the CyberK'NEX does not have the same degree of versatility as the two before mentioned construction tools, and that is mirrored in the educational aspects of this toy by the fact that the user is not able to explore as much.

Tetrixx

Tetrixx is yet another robot development kit, but compared to the kits mentioned previously this kit uses parts that are made of aluminum. Some of the different mechanical parts are shown in Figure 1.15.

Figure 1.15: Tetrixx parts.

The modular kit consists of the following categories of compatible parts:

Mechanical Parts: These are the main building blocks consisting of mainly bars and plates. They are used to build up a solid frame for a car, a walking robot, etc. There are also wheels, axes, and gears.

Electro-mechanical Parts These are motors, servomotors, switches, batteries, sensors, etc. which make a model move and react.

Controller The robots brain consists of a micro-controller board holding different expansion boards used to control actuators and sensors.

Special Parts These are specialized bearings for particular parts, e.g. special sensors, pneumatic parts, and so on.

Using these parts, the user is able to build his/her own robots, connecting the different parts with nuts and bolts. Because of this, the Tetrixx robots are certainly much more robust than the previously described robot construction toys. An example of a Tetrixx robot can be seen in Figure 1.16. This figure shows a spider-like robot that uses 12 servo motors to control the movement of the legs. The control of 12 servos can only be established through a servo expansion board. The modularity has been implemented into the controller board as well, which allows connection of different kinds of expansion boards.

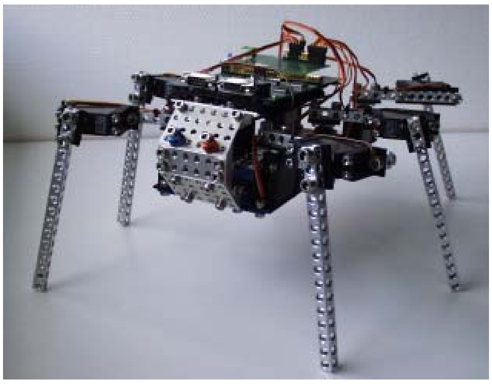


Figure 1.16: A Tetrixx "spider" robot.

As this robot construction kit still is in its early stages, no user friendly programming language has been implemented, and there is still no places where this kit can be bought yet.

The educational values of this kit is mainly to teach children mechanics, electronics and programming through the implementation of robots according to the producers. With regards to the entertainment factors, the fun will be in creating and testing ideas either in groups or alone.

GRO-BOTS

Gro-bots is also a construction toy based on the building units of the Expandagon System. This system consists basically of the three different units shown in Figure 1.17. The idea of the expandagons is, that they have two states, namely open and closed. The single units can then be snapped together using a small set of connectors, and in this way the user can build structures that will expand when a certain so-called Magic Point is pressed. The expansion from the Expandagons into the GRO-BOTS comes with the implementation of a motor into the construction. The current version of the GRO-BOTS allows the user to control one motor with a remote control and in that way change the morphology of his/her construction.

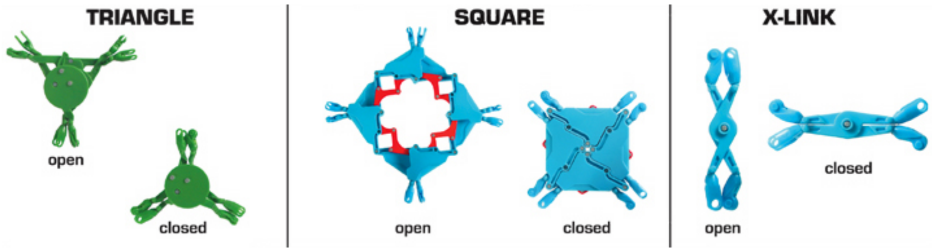


Figure 1.17: The basic Expandagon building units.

The way the Expandagons work is the following: each piece of the object is part of the folding mechanism. If you look at an Expandagon, it is made up of many separate pieces, and all of them have a job to do. Each Expanda-Triangle is made up of 12 different plastic links held together with 9 pins. Each Expanda-Square is made of 24 links and 20 pins. Each piece contributes to the expanding-contracting mechanism. That's why you can make such complex, dynamic shapes with just a few Expandagons.

The edutainment aspects of this construction toy, is that children learn about geometry through their play with these geometric building units, and the amazement of expandability makes this toy fun to play with. An example of a GRO-BOT can be seen in Figure 1.18.

Figure 1.18: A GRO-BOT figure in non-expanded and expanded mode.

RCS-6

This is a Robot Construction Set from the ROBIX company. This set is designed for use by educators and students. The set makes use of a PC for doing the movement calculations and miscellaneous robot parts, that are mainly based on servo motors, and which can be connected into several different robotic structures. One example of a mobile robot is shown in Figure 1.19, where this structure has to stay connected to the PC in order to make any movement. Because of the wire dependency, however, most applications for this construction set make use of stationary robotic structures, like traditional robot link and joint arms. An example of a stationary robot can be seen in Figure .

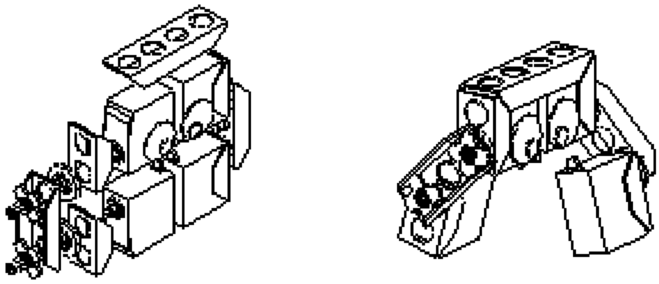


Figure 1.19: A RCS-6 robot.

The software delivered with the RCS-6 has two modes. The first mode is a traditional sequential edit mode, where the user can edit, cut and paste sequences together to produce correct movement behavior for the robot. The other mode is teach mode, where the user can teach the robot what to do without typing anything. In this mode, the user records robot movements which can then be combined into a sequence and make the robot do its job.

The educational factor of this construction set is to teach children robotics, both on the creational level as well as the behavioral level, which means that children both have to build and program the robot. Meanwhile the children learn things like mechanics, mathematics and programming.

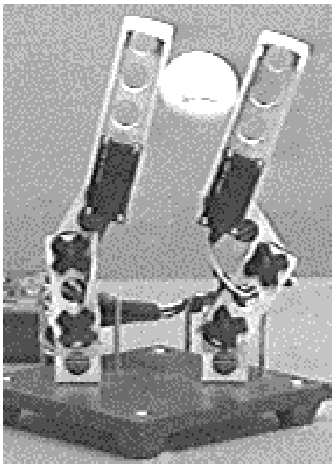


Figure 1.20: A RCS-6 gripper robot.

Summary

As can be seen, there are numerous edutainment robots on the market, and most have emerged on the market recently. Some robots offer little possibility for interaction and construction as some of the first robots mentioned. Many of these systems are *closed systems* that are predefined by the manufacturer. However, some robots offer the possibility of changing the behaviour during the interaction by the user. This is a fairly limited change, since it only happens on the behavioural response on the robots. Finally, some robots offer the possibility to manipulate with both behaviour and physical structure of the robotic system. These are more *open systems* than those robotic systems with predefined behaviour and/or morphology.

1.1 Other edutainment robot toys

The following page shows some of the many other robot toys and kits available. The market for such robots has increased during the last couple of years, so many more, similar robotic toys are available.

DinoChi by Tiger Electronics

i-Cybie dog by Tiger Electronics

Cyber Spider by Wow Wee Inc.

Bot-Ster by Tiger Electronics

IColors Mega-Byte by Wow Wee Inc.

Robot Baby by Tiger Electronics

CommandoBot 3 by MGA Entertainment

Bow Wow Buddies by MGA Entertainment

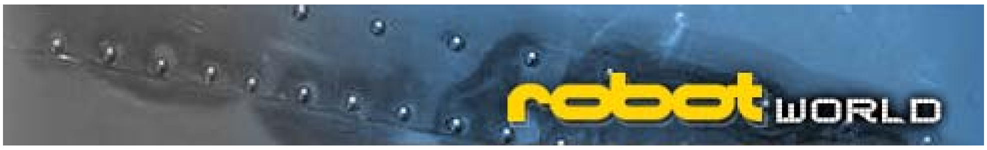
Robotic Arm Trainer by EK Japan

Soccer Pro by EK Japan

SolarSpeeder by SolarBotics

Logiblocs by Logibloc

1.2 *Edutainment robot web-sites*



This website, which can be found at http://www.bbc.co.uk/science/robots/ supplies information about the field of robotics through several interactive presentations. Besides historical and technical information, this site also holds information and building instructions for several different robots. Kits for these robots can be bought online through the Build-a-Bot sub-site. The robots include:

- Three types of driving robots.
- An IQ robot.
- A Sensory equipped robot.
- A robot with PC interface.
- A robot crawler.
- A robot walker.

The Techno Games part of the BBC RobotWorld site specifies rules for different competitions in which teams can participate with their home-built robots. The categories are e.g. football, cycling, swimming and long jump etc. The competitions are designed to test the ingenuity, creativity and mechanical mastery of Britain's schools, colleges, universities, families, community groups, businesses and individuals.

The Technocopia sub-site explains the different fields of robotics, including the biologically inspired robots, industrial robots, toy robots and robots known from film. In this way people are given a up-to-date view on robotics as well as a clear distinction of what real robots can do today as opposed to those used in science-fiction movies.

The Robots in time sub-site describes the historical aspects of robotics both with respect to technologic progress and important people in robot science.

The Robot Review sub-site is a monthly column featuring news and stories about the world of roboteering. Here more can be learned about the latest developments from today's inventors and robot enthusiasts.

The Robots@school sub-site is a resource that is full of ideas to help teachers cover areas of the National Curriculum in an informative way for children of all ages.

The Robot Gallery sub-site provides visual information by pictures and movies, of all kind of robots – both industrial, consumer and entertainment robots such as e.g. the SONY AIBO.

2 Psychological Aspects

Before developing new edutainment set-ups, it is important to reflect on the psychological and educational aspects that follow educational robotics. Most of the current literature, when evaluating the educational power of robotics, refers to two main theories: Piaget's Constructivism [6, 7] and Papert's Constructionism [8, 9]. It is not very easy, from the psychologist's point of view, to distinguish the latter from the former since with different words they describe very similar principles and cognitive attitude of the learning and evolving human mind. To make it extremely simple, they both stress the importance of learning by manipulating the surrounding environment. Anyway, despite of definitions, both theories consistently describe and explain the successful results one obtains when giving children the chance to learn by handling physical objects (e.g. robotics nowadays), and the very same arguments can be brought to explain the educational validity and value of a robotic game such as RoboCupJunior. (For example, it is to be noticed that RoboCupJunior can be structured in such a way to easily differentiate, in a Piaget's fashion, different levels of access accordingly to different mental ages). Also, we should consider how edutainment robotics implements Vygotsky's idea of viewing knowledge as a process, which basically depends on technological and cultural scaffolding [10]. Nevertheless, we would believe that there is also something else that contributes to making edutainment robotics successful, though we cannot present a fully elaborated theory. However, the experience [1,2,3,4,5] tells us something more about learning mechanisms. First of all, it is a reminder of the importance of the edutainment approach, namely to bring fun within a learning context. That is something more than simply manipulating: it is to enjoy manipulating. Secondly, the first approach to the game/interaction is relevant. The game/interaction should be easy to discriminate, recognize and understand. The younger the children are, the more important that aspect becomes. At the very first sight, children should know what the game is about, how much fun they might get out of it and, loosing no time for understanding new rules, they will engage themselves in having the robots doing what they want them to do. In other words, they will be able to concentrate themselves on building a suitable robot. As a side effect, educators will feel comfortable with the game in the very same way. That is important, too, since parents' or teachers' motivations, drives and, oppositely, stresses might be directly reflected on to the children's ones.

Further, the relevant role of the game surrounding should be underlined. We believe that there may be big potentials in developing robotic games that can potentially host a very rich context (like for example in the LEGO Stadium for robot soccer). This can easily raise children's interest and might give them the possibility to move their attention from the game contest, the most competitive aspect of the game, to the design of the robots and the stadium, a much more cooperative, relaxed and creative aspect of it. A direct consequence of this is that the RoboCupJunior setting might fill out many other psychologically needs such as identification, projection, etc. that, although not missing, cannot be said to characterize the game as unique. Further, it is essential to recognize the entire psychological panorama on the importance of manipulating moving objects, whose autonomous motion is partially driven by us, as well as the emotional attitudes and individual differences of children in and out of a social context.

Though autonomous robots playing soccer, dancing and making summersaults may be nice demonstrations, there is a major drawback if they do not allow the interaction by the users. This is a major drawback when we are concerned with children learning by getting hands-on experience. Indeed, there may be a conflict between much modern research on developing autonomous systems, and the educational research putting emphasis on interaction, e.g. in guided constructionism [11]. Also, classical constructionism with its roots in the work by J. Piaget suggests that the best way to learn about an artefact is to actually build the artefact.

The same concern regarding the autonomy of autonomous robots is expressed in "Tech Toys. How are they affecting your child?", Child Magazine, February 2001, in which it is questioned whether the new technological toys may in fact "be dumbing down our children's play: stunting their intellectual growth, stifling creativity, shortening attention spans, undermining relationships, and, on top of it all, proving to be a huge waste of money, because the novelty of these high-tech toys can wear off long before their batteries die." A problem arising from this is that we may see an increase in the number of children who have trouble playing cooperatively, who lack empathy, and who crave nonstop entertainment, and David W. Willis, M.D., a developmental-behavioral pediatrician in

Portland, has expressed "The problem is that without enough opportunity for open-ended play like building with blocks or engaging in pretend games, children may not learn the kind of logical thinking and persistence that help them develop problem-solving skills."

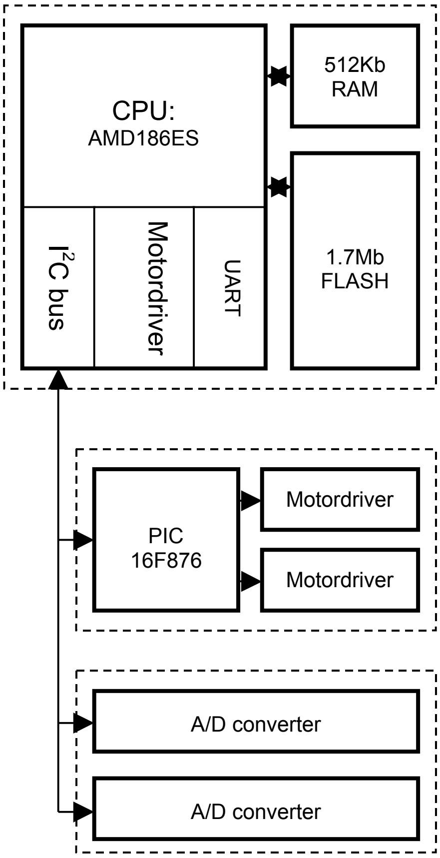
This is one of the reasons that in our future edutainment robotic work, we will work towards the development of new technological tools that support the open-ended play, and try to develop technological building blocks based on the work on the technological more sophisticated building blocks for the autonomous re-assembling behaviour from the HYDRA project (www.hydra-robot.com).

3 Development

In order to explore some of the edutainment robotics issues mentioned above, we engaged in different activities of both developing robots with limited interaction (humanoids), context (RoboCupJunior 2002), new control for re-configurable robots (CONRO robots), and new construction kits for facilitating play with re-configurable robots. Further, the we engaged in an Italian State project on 'Educational Robotics' together with psychologists from University of Palermo, University of Naples II, and University of Cosenza, which supports the work on development of new technological tools in our work by providing a psychological basis and tests for the development of the new tools. Below follows very short descriptions of some of these developments that will form the basis for our future edutainment work.

Viki Humanoids

In some work, we are promoting a new understanding of the way to build complex, electronic artifacts derived from modern artificial intelligence focus on bottom-up approaches. We wanted to investigate how this general approach of designing electronic artifacts bottom-up could lead to new ways for designing humanoids for edutainment. In contrast to the top-down approach of equipping a humanoid with as many sensors, motors, power, etc. as possible, we developed a bottom-up approach to the construction of humanoids. The approach is shown with the development of the Viki humanoid that won the RoboCup Humanoids Free Style World Championship 2002. For the development of the bottom-up approach we looked at the correspondence and interrelatedness between material, electronic hardware, energy use, and control. By finding the right balance and relationship between these components of the system, it becomes possible to develop biped walking and other humanoid behaviours with much simpler hardware and control than is traditionally envisioned for humanoids. Indeed, the Viki humanoid robots were able to win the world championship though they include much less sensors, motors and energy use than their competitors.



Viki's control system is built to be minimalistic in nature, modular and highly reconfigurable. As shown in the figure, the control system is centered around a rather powerful CPU with the peripherals connected on an I2C bus with a single motor controller being interfaced directly to the CPU as the exception. This allows for quick reconfiguration and can be expanded or shrunk as desired for the particular purpose. Since Viki is controlled by five motors four motor drivers with local computational power was attached to the bus along with eight analog to digital converters for feedback from the angular sensors. The entire system is powered by two 3.5 volt lithium-ion polymer batteries connected in series to offer 7 volt.

The CPU in Viki is a AMD186ES micro controller which essentially is an Intel 186 clone wrapped in a micro controller layer that amongst others offer two UARTS, timers and several bi-directional I/O pins. The microcontroller is supported by 512Kb of working RAM and approximately 0.7Mb of FLASH disk for program storage and file-creation. The system runs an embedded DOS compatible with the IBM DOS allowing for program-development on a PC with any DOS compiler.

For feedback on the angular position of hips, the rotation of the legs and the displacements of the arms four commercial linear potentiometers costing 70 US cent each was built into Viki at appropriate places to offer a continuous signal for A/D conversion. Also, a few switches provide feedback for extremity positions. A belt of IR sensors was developed to allow detection of a small IR emitting ball that we developed.

We developed our humanoid robots by first showing that one motor is enough to achieve straight walking and turning [12]. Later, we increased the number of motors when more flexibility in movement was desirable. So the humanoids use 5 motors. Two motors are used for leg turning, one motor for hip movement, one motor for body balance, and one for arm swinging. The humanoid is app. 25cm of height.

Figure 3.2. RoboCup 2002 Humanoids and participants.

For the RoboCup 2002, the Viki humanoids were developed to dance and performed in an autonomous manner. Hence, in that implementation, they can be viewed as belonging to the class of entertainment robots with no or limited interaction possibilities (as Furby, AIBO, etc.). Currently, we are developing user-guided behaviour based interaction systems for the Viki humanoids in order to increase the interaction possibilities. Another experience with the user-guided behaviour based approach is described in the following.

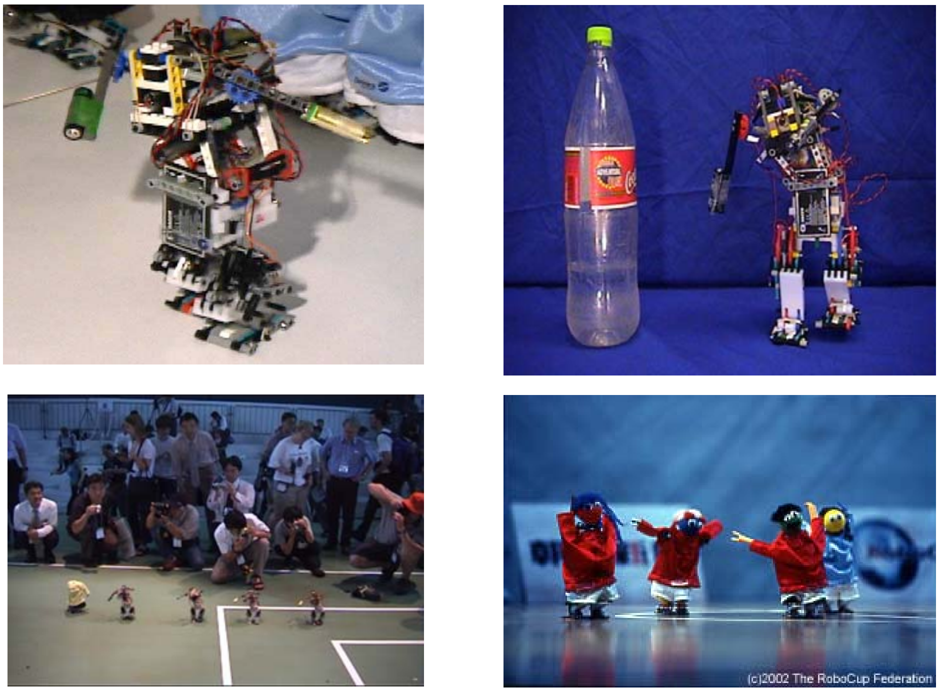


Figure 3.3. The Viki humanoid robots that we developed to explore the principle of coupling between hardware, software, material, and energy use. The Viki humanoid robots won the RoboCup Humanoids Free Style World Championship 2002. The RoboCup 2002 had 117.000 visitors in Fukuoka Dome in June 2002.

RoboCupJunior 2002

For the RoboCupJunior, we developed the game to allow children to get hands-on experience with robotics, and for this purpose we set up a LEGO MINDSTORMS robot soccer game for children. In Fukuoka, Japan, 70 teams of children from 16 different countries participated in our RoboCupJunior tournament. Apart from the soccer games, we also organize robot dance performances in order for the children to be able to create both robots and the context in which they should perform.

Before the RoboCupJunior 2002, we arranged a local tournament in Denmark in order to investigate the suitability of different tools that we developed for edutainment robotics – see http://www.adaptronics.dk/Projects/RobotFodbold/. We developed the *user-guided behaviour-based approach* [1] in order to allow non-expert users to develop their own robots in an easy and fast manner. Indeed, using this approach, children of the age 7-14 were able to develop their own LEGO MINDSTORMS robot soccer players to play in nice and friendly tournaments with 60-90 minutes of development time! The winner of the local tournament was a small boy of 7 years of age, who won the trip to RoboCup 2002 in Japan, sponsored by the RoboCup Federation.

Figure 3.4. The robot soccer tournament for children that we developed and held in Odense in May 2002. Left: One-on-one play, right: 1st prize of trip to Japan handed over to the winning boy of 7 years of age.

In a user-guided behaviour-based system, it is the system developer who takes care of the difficult robotic problems, while the end-user is working on a higher abstraction level by making the coordination of primitive behaviours. So the programming environment for the LEGO MINDSTORMS RoboCup Junior was made with emphasis on allowing children (between 7 and 14 years of age) to develop their own robot soccer players. We found the behaviour-based approach to be an excellent inspiration for achieving this. Especially, we used the concepts of low and high levels of competence, or primitive behaviours and arbitration. We, as developers, provide the primitive behaviours to the children, while they work (play) on a higher level with the arbitration of the primitives. Hence, the difficult task of designing low level primitives that includes sensor interpretation is done a priori by the programmer (so the children get to do the easier and funny part of coordination rather than doing low level programming). For instance, the interpretation of analog values on the input channels is done in the primitive behaviours, which might provide the user with a behavior such as ``Find the Ball''. The designer of the system programs the motors to allow the robot to, for example, turn around and stop when receiving values such as 618 and 355 on two of the input channels. But the user is simply coordinating the primitive behaviours.

Towards edutainment with reconfigurable robots

During the past year, our Ph.D. student Kasper Støy from the Maersk Institute collaborated with Shen's group at Information Sciences Institute, USC on developing control algorithms for producing locomotion in self-reconfigurable robots (and so focused on introducing the basic HYDRA foundation of modern artificial intelligence in the CONRO work and on the use in a demonstrator that gives indication to the possibility of using reconfigurable robots in edutainment). The idea is that an appropriate locomotion pattern can emerge depending on the way in which the modules are connected. This is appropriate for entertainment, because the child can change the way the modules are connected and the robot will automatically pick an appropriate locomotion pattern. For instance, the child can connect the modules in a chain and the robot will move like a snake. Later the child can make a quadruped walker and have it walk. This idea is demonstrated in Figure 3.5 and is reported in [13].

Figure 3.5. The robot first moves using a sidewinder gait (left). The robot is then manually reconfigured into a quadruped walker (middle). Finally the robot walks (right).

The hardware used in this demonstration is the CONRO modules. These were developed at University of Southern California's Information Sciences Institute [14, 15]. The modules are roughly shaped as rectangular boxes measuring 10cm x 4.5cm x 4.5cm and weigh 100grams. The modules have a female connector located at one end by definition facing south and three male connectors located at the other end facing east, west, and north. Each connector has an infra-red transmitter and receiver used for local communication and sensing. The modules have two controllable degrees of freedom: pitch (up and down) and yaw (side to side). Processing is taken care of by an onboard Basic Stamp 2 processor. The modules have onboard batteries, but they supply insufficient power for most applications and the modules are therefore powered through cables.

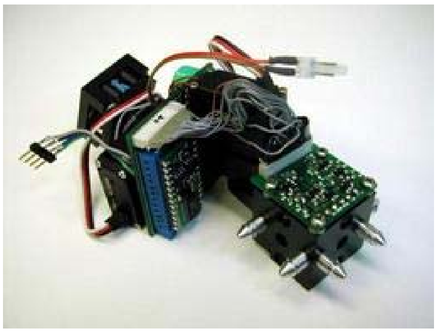


Figure 3.6. A CONRO module

The modules are controlled using role based control [16]. In role based control each module repeats a cyclic action sequence describing the motion of the module. At a specified point in this action sequence the module sends a synchronization signal to connected child modules. If a module receives a synchronization signal it restarts its action sequence. These two mechanisms are enough to produce simple locomotion patterns. For instance, to produce a sidewinder gait each module in the chain make the same oscillation of its actuators, but each module in the chain is slightly delayed compared to the previous one. This produces the overall locomotion pattern of a sidewinder. In general role based control allows the module to select which role to play depending on its local configuration and also in the global configuration tree if needed. This means that more complex locomotion pattern can emerge depending on how the modules are connected.

The simple software building blocks that make up role based control could be represented by different modules and the child could by connecting different modules produce different gaits. Overall this work represents some initial ideas about how to use self-reconfigurable robots in edutainment.

4 Conclusion

In the future development of edutainment applications, we will utilize the experiences that are briefly outlined above. The survey of existing edutainment robot systems tells us that there currently exist three categories of such: those with no construction possibility, those with little construction possibilities and those with extensive construction possibilities. Based on the input from psychologists, we will engage in development of tools for the latter category, since such tools seem to provide the best basis for valuable edutainment for children. Further, they are natural extensions of the HYDRA project work.

Some important ideas about such new edutainment tools is presented in the paper by Lund [17] on *intelligent artefacts*. With the development of intelligent building blocks it becomes possible to ‘program by building’. The construction with intelligent building blocks results not only in the development of a physical structure, but also in the development of a functionality of the physical structure. So construction of functionality can happen with physical building blocks that each contains computational processing and communication.

Only few researchers have engaged in qualitative and quantitative studies of the impact of using robotic toys with children. An important exception is the work by Dautenhahn [18, 19] in the Aurora project (http://www.aurora-project.com). In this project, the research group studies how a mobile robot can become a "toy", and a therapeutic tool for getting children with autism interested in coordinated and synchronized interactions with the environment, and the researchers have engaged in making quantitative studies of the interaction with robotic toys confronted with traditional toys.

Also, in our collaboration with Italian psychologists in the Educational Robotics project, we try to quantify the positive and negative aspects of using robotic tools in education [20, 21], and we will try to follow the same practice in our future work on edutainment.

Acknowledgement. The work presents the ideas of the authors and not those of sponsoring and funding agencies. Part of this work is sponsored by the Danish National Research Council project Intelligent Artefacts, the Italian State Educational Robotics project, and the European Union FET project HYDRA. Other HYDRA partners are University of Edinburgh, University of Zurich, University of Aarhus, and LEGO. Colleagues and students from our AdapTronics group were helpful during the development of this work, see www.adaptronics.dk.

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