Robotics Courses for Children as a Motivation Tool: The Chilean Experience

Javier Ruiz-del-Solar, *Senior Member, IEEE,* and Roberto Avilés

***Abstract*—Encouraging children's interest in science and technology, as well as increasing their technological literacy, may be regarded as one of the educational paradigms of this century. The authors of this paper, affiliated with the Department of Electrical Engineering at the University of Chile, Santiago, have designed schemes to contribute to both goals and set guidelines for curricular and extracurricular school activities related to technology. In this context, this paper reviews their experience concerning practical robotics courses for children developed since 2000. More than 700 children and 90 school teachers have already attended these robotics courses, and the model is now being implemented in several schools and institutions in Chile. The robotics courses evolved to their present form from ideas developed during the late 1990s, mostly in the United States. Some preliminary assessment data is presented to support this approach. Current projects are also outlined. It is believed that the authors' experience might be of interest to engineering schools elsewhere.**

***Index Terms*—BEAM (Biology, Electronics, Aesthetics and Mechanics), LEGO robotics, robotics as a motivation tool for children.**

I. Introduction

THE AIM of this paper is to share experience derived from working with school children using robotics as a tool for fostering their interest in science and technology. Robotics is a highly motivating activity for children. It allows them to approach technology both amusingly and intuitively, while discovering the underlying science principles. Indeed, robotics has emerged as a useful tool in education since, unlike many others, it provides the place where fields or ideas of science and technology intersect and overlap. From this starting point, a range of activities have been developed largely through practical robotics courses with the long-term goal of motivating children to pursue university careers in science and technology, to increase their technological literacy, and to have, at least, technology-friendly adults.

The authors' experience started in 1999, when facing the challenge of designing new and attractive laboratory work for undergraduate students at their engineering school. They thought, possibly, that original and well-designed experiments could become, in their simpler versions, tools to illustrate what engineering means and does in answer to legitimate questions posed by talented children and high-school students visiting the campus.

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The authors are with the Department of Electrical Engineering, University of Chile, Santiago 837-0451, Chile (e-mail: jruizd@ing.uchile.cl).

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They first started working with school children in solar energy experiments, which later was connected to the robotics work of Tilden [1], then at Los Alamos National Laboratories. Thus, they set the basis of their first practical courses on Biology, Electronics, Aesthetics, and Mechanics (BEAM) robotics, carried out in October 2000 and January 2001. Motivated by the positive results of these experiences, they then explored the use of the Parallax Board of Education [2] in a practical course for school teachers during July 2001. In this course, the Parallax board was used for teaching the essential elements of data acquisition, sensors, and robotics.

The Massachusetts Institute of Technology (MIT), Cambridge, experience in developing the *Intelligent Brick* for the LEGO MindStorms set as an expression of the "constructionist learning" ideas of Papert and collaborators of the MIT Artificial Intelligence Laboratory [3]–[5] widened the scope. Practical ways developed in the Robotics Academy at Carnegie Mellon University, Pittsburgh, PA, to work with children using the LEGO MindStorms set [6] as a tool in education, presented an interesting path to follow. Thus, several practical courses of robotics were offered, using LEGO MindStorms during 2002, 2003, and 2004.

The urgent need to educate in science and technology has to be understood in the context of a developing country like Chile. Regardless of the considerable investment in education during the last decade, these school students still perform poorly on the average when compared with those from developed countries [7], [8]. Although Chile ranks reasonably well in some areas of the basic sciences, the results are not encouraging in technology when measured by the number of published papers [9] or the number of patents [10]. A key policy to improve awareness and opportunities in science and technology is sustained investment in the use of information technologies applied to education [11].

The authors have chosen to focus their efforts on establishing new technological spaces for the younger students and opportunities for their mentors. So far, more than 700 children and 90 school teachers have attended at least one of the courses on robotics, lasting from two to five days. As a side effect, some Chilean schools are already planning to set their own robotics laboratories under the authors' guidance. Thus, other engineering schools can reproduce such highly rewarding experiences and strengthen their communities' potential. The basic elements seem to be motivation, a solid background in engineering, and the will to learn through the process of working with children.

Several initiatives have been carried out in different countries with the goal of fostering the interest of children in science and technology using robotics. Some of these efforts have been developed in the United States, Canada, Mexico, England, Germany, France, Japan, Korea, India, Israel, and Australia, for example. In South America, robotic activities for children were found in Brazil [12], Argentina [13], and Peru [14]. Some global initiatives, such as FIRST (For Inspiration and Recognition of Science and Technology) [15] and RoboCup Junior [16], look for sponsors of local, regional, and international robotics events (contests for young students). Most of the previously mentioned initiatives are developed at a school level and not in universities. However, in [17], some applications of LEGO robotics are described for undergraduate and graduate education.

This paper is organized as follows. Section II addresses the problem of encouraging children's interest in science and technology. Section III describes the robotics courses that the authors have organized for both children and teachers of basic and high schools. Section IV presents current projects and the know-how to transfer works from the university environment to Chilean schools and educational corporations. Finally, in Section V, some conclusions and projections of the work are given.

II. Problem Definition

The following five factors determine the economical growth of countries currently:

1) innovation and technical progress;
2) institutions and governance;
3) an openness and integration into the world economy;
4) a stable macroeconomic environment;
5) the joint influences of distance, geography, and costs of trade [18].

As shown by different rankings of competitiveness [19], countries failing to support innovation and develop, or at least introduce new technologies, face many obstacles in sustaining long-term economical growth [18].

Education is recognized as a key factor for achieving innovation and technical progress. It affects the ability of future generations to innovate and integrate countries successfully in a knowledge-based economy. For this reason, the quality and equity of the educational systems becomes the cornerstone for development and, therefore, a problem that should be addressed. Like many other countries, Chile is facing these issues. Among many other initiatives, motivating children for pursuing studies in science and technology and increasing their technological literacy are major efforts.

A. Education in Chile

The recently made compulsory Chilean K–12 educational system is divided in the basic school level (levels K1–K8, with children between 6 and 14 years old) and high school level (levels K9–K12, with teenagers between 13 and 18 years old). A preschool level exists; although highly recommended, it is not compulsory. The investment in education has increased up to 7% of the national gross product in the last 12 years, and it compares well with the average 4–4.5% observed in Latin America. The source of this 7% is public in $\sim$4%; the rest is private investment.

The government policies in public education seek quality and equity for economically deprived students when competing with those from the private system. While the opportunity gap has diminished in the last six years, recent studies reveal that Chile is still far from having a high-quality educational system [11]. Indeed, the students do not perform well on an average when compared with those students from other countries, especially in science tests [8]. However, the authors are optimistic. Some current initiatives show that improvements do exist. As an example, the project ENLACES [20], designed to connect all public schools to the Internet, has achieved a 100% networking of high schools and 50% of basic schools.

B. Reverting the Situation

As an engineering school, the main contributions should come from its own strengths. Then, a natural approach focuses on encouraging children's interest in science and technology and advising curricular and extracurricular school activities in science-and-technology-related areas. In this context, the robotics courses make a contribution in both directions, beyond initiatives like summer schools for 1500 K10–K12 children and training courses for math and physics high school teachers that the engineering school organizes yearly.

Robotics and children come together nicely and provide a good starting point. Then, the use of robotics in the classroom presents many advantages. For example, through the Technological Education Guidelines from Chile's Ministry of Education, one observes that the K8 program works on systems, their mechanisms, and internal circuits, while the K10 program focuses on services, the use of computers, teamwork, and written reports. These requirements are easily embedded into the activities giving shape to the robotics courses.

III. Robotics Courses for Children and School Teachers

This section describes the activities that have been developed with children and teachers around the subject of robotics.

A. Robotics Courses Using BEAM Robots

The first experience with teaching robotics for children was using BEAM robots. The motto was that, in education, "robotics is a way, not an end."

BEAM robots are reactive robots, and they do not need to be programmed because the desired robot behaviors are embedded into the robot structure, i.e., the electrical and mechanical connections of sensors, motors, and effectors. Electronics and mechanics design, rather than programming, is emphasized. In fact, BEAM robots do not use processor and memory components but analog electronics (resistors, capacitors, etc.) and some basic digital components, such as registers and flip-flops. In addition, BEAM robots consume less energy than normal robots, and photovoltaic cells can be used in some cases for powering them.

In the workshops, children learn how BEAM robots work through building and using a robot. The idea is to explore some practical issues, such as photovoltaic cells and solar energy conversion, how a simple dc motor works, and what a capacitor is, rather than providing a full understanding of the engineering ideas behind the robots. The children explore the mechanics of the employed robots. The automation and control, including a summary of the historical development of these ideas, is also addressed. In addition, introduced are the biological hints that are a motivation and challenge for robotics experts.

As a direct by-product of participation in the BEAM Robotics Workshop held in the Santa Fe Art Institute, Santa Fe, NM, on May 3–6, 2000, the first workshop on BEAM robotics was completed in October 2000. In the workshop, 100 K7–K8 children attended. They worked in couples, during two days, using the Solarbotics "Photopopper" robot kit. They learned to perform the following tasks:

1) recognize and handle a set of electronic and mechanical parts provided in the kit (resistors, capacitors, diodes, transistors, dc motors, solar cells, etc.) (among other topics, they learned about the resistor color code, diode polarity, transistor powering and connection, polarity of electrolytic capacitors, and photovoltaic cells connection);
2) follow instructions on how to work with the electronic parts, including working with a soldering iron and measurement instruments (voltmeter, oscilloscope, etc.) for connecting and soldering the electronic components into an electronic plate;
3) follow instructions on how to work with the mechanical parts, including the installation of the electronic plate into the robot body, the connections of the motors, and finally the construction of two antennas;
4) debug and test the final Photopopper robots, including participating in robot contests with other groups.
5) attend talks on robotics and related disciplines.

The results were quite encouraging. The small robots were very attractive to children, who exhibited a well-deserved sense of pride as the result of their efforts. This workshop and further workshops were complemented by talks given by leading Chilean engineers and scientists. They provided a broader view of robotics and related topics, such as mechanics, electronics, biology, artificial life, and computational intelligence. An important conclusion of this first workshop was the need for a "national product" rather than an imported kit, mainly because of economical reasons.

In January 2001, a second BEAM robotics four-day workshop was organized for 100 K9–K10 children, using *made-in-Chile* robotics kits. These robots were the solar-powered "fotopoper" (a version of the Solarbotics Photopopper robot kit) and the battery powered caminante (a version of the Solarbotics Walker Scout I robot kit). The fotopoper can walk forward while avoiding small obstacles and search for light on which to feed. The caminante is a two-servo, four-legged micro-core-based robot, capable of walking forward and backward and avoiding simple obstacles. When children built the fotopoper and the caminante, they worked with real components and not with a kit. They built all mechanical parts by themselves. The robot body was made using a piece of wood, the robot legs were built using thick wires, and antennas were built using thin wires. Children did more than putting components in an electronic plate;

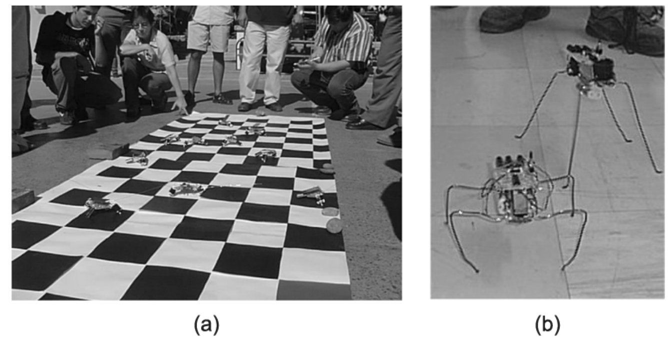

Fig. 1. Photos from the BEAM workshops. (a) Group of teachers test their fotopopers in the January 2001 workshop. (b) Two caminante robots (a micro-core-based robot) are built by children in the January 2001 workshop.

they really built the robot. Afterwards, they connected all mechanical and electronic components. They could see how aspects like precision, materials, shape, and symmetry influence the final performance of a mechanical device.

In January 2001, the first BEAM robotics workshop for school teachers in physics, arts, biology, electronics, education technology, and mathematics was conducted. A group of almost 50 teachers worked with the same two robots—fotopoper and caminante. The idea was that these teachers could replicate these workshops at their schools afterwards.

At this point, hand in hand with these robot workshops, the authors started a Mechatronics Laboratory in March 2000. This laboratory is both the location to work on adaptations and the development of new robots and also the right place to recruit engineering students who help work with the children. In the workshops, normally, one engineering student monitors every 15 participants.

An important characteristic of the BEAM workshops is that all participants, either children or teachers, take home their robots, a highlight of the program. Students can review their work; they can observe the mechanics of the system and think about how to improve it. Even more important, however, they can show their robots to their families, their neighbors, and people in their schools, thus producing a cascade effect of the workshop activities.

In Fig. 1, some selected photographs from the BEAM workshops are shown. More graphical material is available in [21].

B. Robotics Courses Using PARALLAX Robots

Motivated by the success of the BEAM robotics workshops the authors explored the idea of a workshop based on digital robotics. With advice and support from Parallax, Inc., they designed a workshop in data acquisition, sensors, and robotics for teachers based on the use of the Parallax Board of Education, held at the Universidad de Chile in July 2001. In this workshop, they registered an attendance of 40 teachers. They taught the participants to perform the following tasks:

- recognize a set of electronic and mechanical parts provided in a kit and follow instructions for their handling;
- debug and test basic programs, using the Basic Stamp microcontroller;

- develop a microcontroller-based system for data acquisition;
- mount, program, and debug the Boe Bot, a robot based on the Parallax Board of Education.

The workshop was a success, but the costs were far too high to make the experiment sustainable. Searching for alternatives, the authors discovered the LEGO MindStorms kits.

C. *Robotics Courses Using LEGO Robots*

The first approach to the use of LEGO was inspired by Martin's book [22]. A visit to the Robotics Academy at Carnegie Mellon University in February 2002 provided a framework by which to organize robotics workshops based on LEGO kits. In these workshops, the authors used their version of the Robotics Academy materials. The main ideas developed by the Robotics Academy can be summarized as follows:

- help to develop curriculum modules that will reinforce current math, science, and communications standards;
- prepare children to work in a world dominated by technology;
- help teachers to develop a technologically literate workforce;
- develop tools to help teachers integrate workplace competencies into school activities.

The four-day LEGO workshops have the following structure. The first day consists of an introduction to the materials of the LEGO kit 9790 and the essentials of the LEGO Intelligent Brick (the Robotics Command eXplorer (RCX)) programming, using the Robolab visual programming language. Students work around the Tankbot, a basic robot on which children can add sensors, modify and debug computer programs, and perform mechanical improvements. They can also test platforms different from the original Tankbot. Thus, they are encouraged to use their imagination. A working teachers' guide and continuous presence support their initiatives.

The second day goes deeper into the programming aspects of the RCX, e.g., the use of variables, timers, and different sensors. The third day focuses on mechanics, emphasizing design aspects and concepts, such as speed versus torque, the use of legs, and others. The fourth day is divided in half. The first half is competition time (the fast bots using wheels or legs, etc.). During the second half, children design and mount a free project they show during the open-door evening to family members and friends they have invited. During the workshop, children work in groups of four. Each child takes a different role that changes every day. The four roles are project manager, programmer, information specialist, and materials manager.

The LEGO workshops have been very successful. Three of these workshops have already been organized for K7–K8 children and three for K9–K11 children. Roughly 90 students participated in each workshop. Staff members of many schools and the Ministry of Education personnel, including the Minister, have visited them and have shown great interest in replicating these activities. The EXPLORA program [23], the main government initiative in charge of science and technology activities with children, has also shown considerable interest in the workshops.

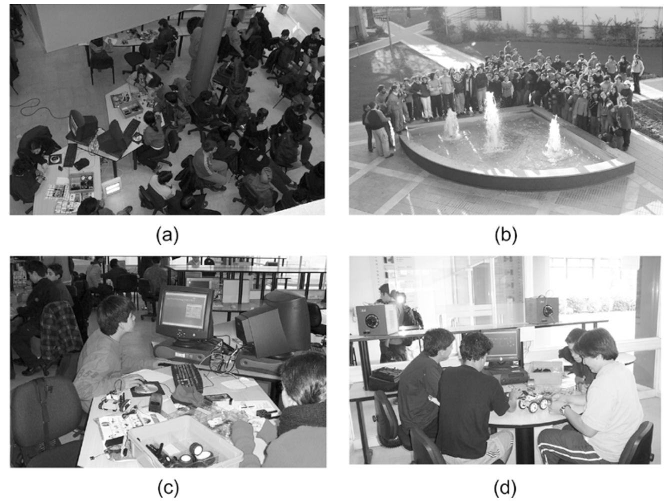

Fig. 2. Photographs from the LEGO workshops. (a) Students working during the July 2002 workshop. (b) Large group of K7–K8 children in front of the laboratory building during the July 2002 workshop. (c), (d) Two groups of K9–K10 children working on programming tasks and the mechanics of their robots during the January 2003 workshops.

A graphical review of this experience is available at the website [21]. In Fig. 2, four selected photographs from the LEGO workshops are shown.

D. *Preliminary Results and Assessment Data*

In order to evaluate the workshops (teachers are excluded from this evaluation), the authors conducted a three-question poll: the first question tested the degree of child satisfaction with the workshop, the second inquired about the level of completeness of the developed work (this question was also answered by the children's monitors), and the third question sought to determine the children's interested in eventually pursuing an engineer career. The survey was carried out after each workshop, either directly or through the Internet. The results are summarized in Table I.

The results validate a subjective impression about the high interest of the children in these activities. In the case of the BEAM workshops B1 and B2, the percentage of completeness of the work was lower since the construction of these robots requires working with analog electronics and with measurement instruments. Children had no previous experience in these topics. Children's self-motivation seems to be the key element for their success during the workshop. Unmotivated children do rather poorly. The group structure also plays an important role. Best behavior occurs when previously unknown participants meet each other for the first time during the workshop to form a working team.

Another issue is that robotics contests among groups are highly motivating. Children get extra stamina for performing a good work should "the group's robot defeat all other robots." Every day, different robot contests were organized: the fastest robot with wheels or legs, the strongest robot (a kind of sumo contest), the fastest robot leaving a labyrinth, and others. Every contest gives points to the groups leading to identify the three most successful of the workshop.

TABLE I
GENERAL EVALUATION. Bi CORRESPONDS TO THE BEAM WORKSHOP i; Li CORRESPONDS TO THE LEGO WORKSHOP i. THE NUMBER OF PARTICIPANTS IS IN BRACKETS

Questions	Workshops								
	B 1 (100)	B 2 (100)	L 1 (90)	L 2 (90)	L 3 (90)	L 4 (90)	L 5 (90)	L 6 (90)	Mean
% Satisfaction with the workshop.	85	90	95	93	90	93	95	95	92
% Completeness of the work developed.	65	85	94	93	92	94	92	94	88
% Interest in pursuing an engineering career.	83	90	88	85	87	90	85	83	86

TABLE II
GENDER COMPOSITION OF THE PARTICIPANTS IN THE WORKSHOPS. Bi CORRESPONDS TO BEAM WORKSHOP i; Li CORRESPONDS TO LEGO WORKSHOP i. THE NUMBER OF PARTICIPANTS IN EACH WORKSHOP IS IN BRACKETS

Composition	Workshops							
	B 1 (100)	B 2 (100)	L 1 (90)	L 2 * (90)	L 3 (90)	L 4 (90)	L 5 (90)	L 6 (90)
% Women	30	35	30	4	27	30	21	25
% Men	70	65	70	96	73	70	79	75

* December 2002 was a special situation. 75% of attendants were male students of the same school.

The children worked with free projects during the fourth day of the LEGO workshops. These projects reflect the high quality of the work developed by the children and the ideas they assimilated during the workshops. A summary of successfully developed projects includes a robot that can move across any given labyrinth without the help of a map; a robot that moves over a flat table without falling off of the table; an elevator robot that senses a load, takes it to a given height, and then comes back to the starting position; a robot that can follow the irregular shape of a wall; a robot crane that senses, takes, and moves a given load; and a robot with a gripper that can detect an object, pick it up, and move it to a given location.

A final interesting note is the gender issue in the workshops. In this society, females have less opportunities for having a good-quality scientific education than males, and the authors would like to help solve this discrimination. For this reason, since the beginning of the work with children, they have tried to attract as many female participants as possible. As shown in Table II, the percentage of female participants is between 25% and 30%. The L2 case is anomalous because that workshop was mainly addressed to an all-male school. These numbers compare positively with the 18% of female students in the engineering school and with the 5% in the Electrical Engineering Department.

IV. CURRENT PROJECTS AND KNOW-HOW TRANSFER

Last year, the authors started a website [21]. The website has now become the obvious way to keep former students informed about present and future activities. At the same time, it provides a window of opportunities for newcomers. An online syllabus is planned for teachers disseminating robotics in their academic units.

Besides the organization of LEGO workshops, during this year, the authors will start working on Robotics Clubs, which will function on Saturdays. The objective will be to work with a smaller group of children in BEAM robotics projects that might be developed in just two or three sessions. Besides the evident success of the LEGO workshops, having the children work in a project they can later take with them to their homes is important. There is a multiplicative effect in that children can show their work to their neighbors, school friends, relatives, and teachers. However, a club that works on Saturdays in the Engineering School might not be useful for kids who live too far from Santiago. Thus, translation of those ideas into something that a larger group of students and teachers can share through the Internet would be of value. A project might be developed with materials available across the country. Another possibility is producing a robotics kit that can be distributed through mail. The authors are working on these ideas.

The most ambitious project is being developed in partnership with MIM (Museo Interactivo Mirador) [24], Santiago, Chile, an interactive science and technology museum. Based on the experience gathered, the museum will start activities based on the use of LEGO kits, including robotics workshops. The novelty of these workshops is that they will be addressed to complete school classes and not to a single child. A complete school class will come for half a day to the museum for specific training. This activity will be complemented with pre- and postworking sessions at school. The technology teacher of the class will guide these sessions. Thus, the workshop contents will be integrated with the technology class contents. The technology teachers involved in the program will be trained in the museum one month before the children come to the workshop. This project is very ambitious, but it is already starting. During September 2003 the first 12 teachers and eight monitors from the museum were trained. The project is designed to provide two workshops daily after its first year running, reaching a yearly attendance of 9600 children.

Currently, some schools in Santiago are starting similar projects and setting up robotics laboratories, motivated by teachers or even children who have participated in these workshops. An interesting project is being developed by a private educational corporation in one of the poorest areas of Santiago (Quinta Normal) with the authors' collaboration. The plans are to set up a mechatronics laboratory that would be used by children in levels K7–K8 from nine schools of the corporation. Among other activities, BEAM and LEGO robotics courses, as well as experiences based on the use of the Parallax Board of Education, will be conducted in this laboratory, using all the know-how the authors have developed. Associated activities would be periodic visits to the departmental state-of-the-art laboratories and to some factories around town. (The project is sponsored by a local corporation of industrial companies.) These visits are to motivate children to think about how to apply robotics and to introduce general technology in standard processes that are used in the factories they will visit.

V. Conclusion and Projections

In this paper, the authors have reviewed their activities concerning practical robotics workshops for K–12 children, developed since 2000. The goal of their activities is the fostering of children's interest in science and technology, by increasing their technological literacy and developing curricular and extracurricular school activities related to technology. The authors have more than 700 children and 90 school teachers who have participated in the courses, and currently some schools and institutions in Chile are developing similar courses based on their experience.

Since the beginning of their work with children, they were impressed by the excellent reception of these ideas and activities by the students and teachers who have attended their workshops. The following are some indicators about the success of their workshops for children.

1) 92% of the participants say they are satisfied with the workshop.
2) 88% finished all the basic tasks during the workshop.
3) 86% indicated they will follow an engineering or science university career in the future.

Since the authors started their activities in 2000 and are working on a long-term project, they do not have formal assessment indicators of their activities, but they see the interest of the workshop participants and know that some schools and public institutions are following their steps. They realize the need for assessment indicators measuring the long-term impact of their workshops and are working in that direction.

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Javier Ruiz-del-Solar (S'88–M'97–SM'04) received the engineer degree in electrical engineering and the M.S. degree in electronic engineering from the Technical University Federico Santa Maria, Santa Maria, Chile, in 1991 and 1992, respectively, and the Dr. Eng. degree from the Technical University of Berlin, Berlin, Germany, in 1997.

He became an Assistant Professor of electrical engineering at the University of Chile, Santiago, in 1998 and the Director of the Electro Technologies Laboratory in 2001. His research interests include mobile robotics, image processing, face analysis, and application of soft-computing technologies to computer vision and pattern recognition problems.

Roberto Avilés received the Bachelor in Physics degree from the University of Chile, Santiago, in 1991.

He was in charge of the Electromagnetism Laboratory of the Physics Department of University of Chile from 1996 to 2001. Since 2002, he has been in charge of the university's Electro Technologies Laboratory. His research interests include sensors, analog electronics, and radio techniques.