Social Robotics in Education: State-of-the-Art and Directions

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Abstract. Social Robots is one type of cyber-physical systems, that is the social equivalent of "industry 4.0" technology, in applications involving humans e.g. in businesses of services. Our interest here is in applications of Social Robotics in education. This paper provides a road map regarding commercial social robots currently available in education. Recent literature is included regarding (a) analysis and evaluation of the effectiveness of social robots in education in terms of design specifications such as processors, sensors etc., (b) advantages and drawbacks of various robots currently used in education in terms of cost, impact and usability and (c) future potential directions of interest concerning educational robotics. Our study indicates that an effective design of interactive, educational robots calls for robustness and standardization, of both hardware and software. Novel modeling methodologies might be necessary. Future challenges in the field are also discussed.

Keywords: Educational Robots, Commercial Robots, Evaluation Methodologies, Review.

1 Introduction

In recent years, robots attract considerable attention and become ever more popular in numerous applications [1]. Among the many applications, educational robotics acquire an increased interest in education of all levels [2]. The Japan Robotics Association (JRS), the United Nations Economic Commission (UNEC) and the International Federation of Robotics (IFR) report an increase in the market of personal robots, including educational robots [3]. The interest of the European Union in social and educational robotics also increases steadily. For example, our research team already participates in two recently funded European projects, namely CybSPEED [4] and RONNI [5].

This paper presents comparatively a literature review of commercial robots in education including pros and cons. It also delineates potential future directions of interest in the region (i.e. the Balkans) as well as worldwide. The novelty of this work is that it examines and evaluates commercial social robots from two different perspectives, including, first, design specifications and, second, empirical results of their application in education during the past two years.

The layout of this work is as follows: Section 2 provides an overview on the robotic platforms available in the market including advantages and drawbacks. Section 3 presents recent applications of robots in education. Section 4, discusses challenges in the design of robots as well as proposals for potential future directions. Conclusions are summarized in Section 5.

2 State of the Art of Commercial Robotic Platforms in Education

This section reports the commercial robots developed for educational purposes and summarizes design specifications. Based on design according to a recent review paper [6], robotic platforms can be divided into (1) brick-based robot assembly kits (Mindstorms, VEX IQ, etc.), (2) minimal mobile robot design kits (Arduino Starter Kit, Boe-Bot, etc.), (3) programmable robot manipulators (Servorobotics RA-02, Lynx AL5x, etc.), (4) open-source mobile platforms designed from commercial off-the-self components (MIT SEG, Harvard Kilobot, etc.), (5) fully-assembled commercial mobile robots (Thymio, iRobot Create, etc.) and (6) open-source miniaturized swarm robots (Robomote, Alice, etc.).

This work does not mean to be extensive and exhaustive, since commercial robots are numerous. For this reason, seven robotic platforms have been selected and presented according to the following criteria: (1) most recent reports, only in the past two years, of the bibliography regarding educational experimental researches that utilize these robots, (2) age to which these robots are addressed, so as to cover all the range of all K-12 education and university. According to the above, the selected robotic platforms are: Lego Mindstorms [7], EZ-Robot JD Humanoid [8], Vex IQ Robotics [9], NAO [10], Bee-Bot [11], Romibo [12] and Thymio [13]. The provided information is presented comparatively, and it aims to assist educators and researchers in the selection of the most efficient platform, among the seven presented, according to their needs.

2.1 Design Specifications

This section summarizes the design specification of the selected commercial robots developed for education, in terms of processor, programming language, sensors, connection, encoder, battery and cost. Table 1 lists all the above information.

Table 1. Comparison of selected commercial robots regarding design specifications.

Robot (Release Year)	Processor	Programming Language	Sensors	Connection	En-coder	Battery (Hours)	Cost	Ref.
Lego Mind-storms EV3 (2013)	TI Sitara A M1808 (ARM926E J-S core) @300 MHz	EV 3 Soft-ware	Speaker, Touch, Colour, IR, Motors, Gyroscope	USB Wi-Fi Bluetooth	Yes	x	$350.00	[7]
EZ-Robot JD Humanoid (2013)	32-bit ARM Cor-tex	EZ-Builder, Robo-Scratch, C++, C#, Visual Basic	Motors, Camera, Ultrasonic, Orientation	USB Wi-Fi	x	x	$429.99	[8]
Vex IQ Robot-ics (2006)	ARM Cor-tex-M4	Robotc, Modcit Visual pro-gramming	Speaker, Touch, Colour, Dis-tance, Motors, Joystic, Gyro-scope, Radio	USB Bluetooth	Yes	x	$439.99	[9]
NAO (2008)	Intel Atom with 1.6GHz	C, C++, Matlab, Java, Python, Urbi, .Net, Chore-graphe	Cameras, Tactile, Speaker, Mi-crophone, IR, Sonar, Bump-ers	Ethernet, Wi-Fi	Yes	1-1.5	$9000.00	[10]
Bee-Bot (2011)	x	Directional intuitive language via buttons	Touch, Sound, Light sensors	USB	x	4	$123.00	[11]
Romibo (2013)	x	SD Cards with ques-tions and phrased	Light sensors, IR, Acceler-ometers	USB Wi-Fi Bluetooth	x	x	$649.00	[12]
Thymio (2011)	PIC24FJ1 28	VPL, Blockly, Aseba Stu-dio, Asebascratch	IR, Touch, Accelerometer, Thermometer, Microphone, Motor, Speaker	USB Wi-Fi	Not di-rectly	3-5	$193.50	[13]

2.2 Advantages and Drawbacks of Existing Robotic Platforms

When reviewing commercial robotic platforms, aspects such as ease-of-use, power, expandability, versatility, reliability, universal appear and integration with other technologies, must be taken into consideration.

Lego kits are the most commonly used according to the literature, in all K-12 and universities. Assembly is their basic feature. Their modular design allows students to create their own robots, thus, helps them improve their visual spatial skills and stimulates them to experiment and innovate. They come with a variety of sensors and allow further expansions. Additionally, Lego programming is easy to learn, both for student and teachers. On the other hand, modular design is considered as a disadvantage, since brick components easily go missing. Moreover, there are limited inputs for sensors, thus, the range of potential learning and real-world applications are limited [7].

EZ-Robot combines the versality of a platform, while, due to its appearance, it provides emotional connection with the user. It provides 16 degrees-of-freedom (DOF), a wide-range of learning opportunities and can be used from all ages to create real-world applications through a friendly programming interface. Additionally, it allows children to elevate their programming skills since it can be programmed starting with Robo-Scratch, to C++, C# and Visual Basic [8].

Vex IQ is another modular robotics platform that allows students to perform traditional-style programming. It includes simple programming languages and has a sufficient number of ports and variety of sensors. One of Vexs' drawback is its modular design, that is not appealing for a broad range of children [9].

NAO on the other hand, is a humanoid robot with high degree of appeal for children. It is used in real-world robotic applications, such as in special treatment and special education, to engage children with learning difficulties and enhance the therapeutic process. It provides 25 DOF, several languages for programming, including C++, Matlab, Java, Python, .Net Framework, and a graphic interface, Choregraphe. However, programming is demanding and thus, it is intimidating for teachers and students. Moreover, its price is not affordable for many educators, and even if purchased as educational robot in the classroom, it would be on finite numbers, one or two in the same classroom. For this reason, NAO is more appropriate in University level and research, rather than in typical K-12 education [10].

Moreover, in general, low processing power of commercial social robots and their low-resolution embedded camera insert additional drawbacks in object recognition that need to be addressed.

Bee-Bot is a robot designed for use only by young children. It is easy to operate, friendly in programming using the buttons on its back, appealing appearance and affordable. It is used in teaching sequencing and control, positional and directional language, program sequences and repetitions, and understanding of algorithms [11].

Romibo is remotely controlled, socially assistive robot, with mobility, speech, gesture and face tracking. It is used to train social and academic skills, but usually utilized in special treatment [12]. Thymio is a small robot which allows children to learn a robot's language. It is affordable, very easy to program and allows numerous experiments [13]. These last robots are non-complex and refer to younger children.

In general, the more complex the robot, the easiest to malfunction. A recent study tries to explore the causes of breakdowns in children's interactions with a robotic tutor [14]. The results comprise four themes to explain why children's interactions with the robotic tutor break down: (1) the robot's inability to evoke initial engagement and identify misunderstandings, (2) confusing scaffolding, (3) lack of consistency and fairness, and finally, (4) controller problems. These breakdowns need to be rigorously addressed in order for robotic tutors to be able to feature in education.

3 Analysis and Evaluation of Commercial Robots in Education

The technological development of the 21th century, have increased the use of multimedia tools in education, in other words, commercial robots are used more in the classroom. According to [15] children are also playing with robotics during their playtime. For this reason, analysis and evaluation of the commercial robots in education is considered necessary, so as to investigate the influence of robotics on children's cognition, language, interaction, social and moral development [16]-[18]. The present work aims to help research on robotic applications to education needs according to the previous two years, in order to guide the way for future studies.

3.1 Overview of Application of Robots in Education

In this section, an overview on the most recent results of applications with the selected social robots for the past two years, takes place. Table 2 summarizes the most recent reported results of the bibliography, regarding the use of each selected commercial robot in educational real-world applications.

3.2 Advantages and Drawbacks of the Use of Robots in Education

Educational theorists [26] claim that robotic activities may improve classroom teaching. However, the empirical evidence of the impact of robots in education is considered limited [27]. Without research evidence to support the influence on students' academic scores, robotics in education may be characterized as a current trend [2]. The reported outcomes on the use of robots are in most of the cases descriptive, since they are based on reports of educators regarding individual initiatives, involving a small sample of participants and not integrated into official classroom activities [27].

Another reported drawback in the literature is that most of the applications utilize the robots as an end, or a passive tool, in the learning activity where the robot has been constructed or programmed [28]. Giving more autonomy in robots, in sense of intelligence is one of the future challenges in the design of robotics and it is discussed in an upcoming section. Moreover, the range of possible applications in education is rather limited, since they focus mainly in enhancing development and programming skills, rather than engaging more people by introducing a wider range of activities, connecting with more disciplines and interest areas such as music and art [29].

Table 2. Comparison of selected commercial robots regarding results in educational application.

Robot (Study Year)	Age	Area of Interest	Reported Results	Ref.
Lego Mindstorms EV3 (2016)	18+	Increase motivation on computer science in a bachelor course in mechatronics	Students had to program too much and lost the actual content of the exercises. Motivation and fun factor were not increased, due to the workload for the EV3 programming.	[19]
EZ-Robot JD Humanoid (2016)	18+	Social engagement via data elicitation and interaction games	This work tries to explore how humans' engagement with a social robot can be systematically investigated and evaluated. Only 62.5% of the participants displayed engaging behaviours.	[20]
Vex IQ Robotics (2017)	12+	Enhance high school students' learning about biomimicry and Swarm/ multi robot systems	Students developed an understanding on the characteristics and scope of technology, of engineering design and problem solving.	[21]
NAO (2017)	8+	Treatment of children with autism through imitation games	Preliminary application results suggest that robot-assisted treatment can improve children behaviour. Therapeutic objectives included improvement in social communication and interaction skills, joint attention, response inhibition and cognitive flexibility. Experiments confirmed that a social robot is more readily accepted than a human, by a child with autism.	[22]
Bee-Bot (2017)	5-6	Evaluate the short-term effects in preschool children of an intensive educational robotics training on executive functions	The main finding was a significant improvement in both visuospatial working memory and inhibition skills, with a significant effect also on robot programming skills. These data provide scientific support to the hypothesis that educational robotics are suitable in progressively improving abilities in planning and controlling complex tasks in early childhood, fostering executive functions development.	[23]
Romibo (2017)	5-7	A long-term study to promote STEAM (Science, Technology, Engineering, Arts, and Mathematics) education in an elementary school.	Children played with the robots, constructed robot models with clay, and wrote and acted in a theater production with robots. This technique of using robots as actors in children's theater productions has significant potential for educating children in a number of fields under the STEAM paradigm.	[24]
Thymio (2017)	7-8	To teach computer science (CS) with robotics to four second-grade classes	The goal was to investigate the extent to which students actually learn CS concepts. Findings revealed that students at such an early age were very engaged during the robotics activities and were highly motivated to succeed. Furthermore, these young students do learn CS concepts but find it difficult to create and run their own programs.	[25]

There are studies reporting that the use of robotics has not brought significant increase in student learning [30]. A newly emerged negative factor is the stakeholder's perception of educational robotics [31]. Research studies [32], [33] investigated the perception of parents, children and teachers on the use of educational robotics. Results revealed that most of the parents felt less confident when playing and teaching their children by using robotics. This is due to the luck of technological skills by the users. It is obvious that meaningful benefits will only be obtained if technology is used skillfully by teachers, aligning the provided tools with each students' educational needs [34]. This fact reveals another drawback; the lack of investment in well-trained educators, comfortable with robots and programming [35]. Emphasis must be given in the correct guidance and the role of teachers, since teachers motivate, stimulate and influence students in their school work [36].

On the other hand, results regarding the use of robotics in education are, in total, positive. Recent studies [16] reported that robots encourage interactive learning and makes children more engaged in learning activities It is also reported that in education, the use of robots can potentially help children to develop various academic skills e.g. in science understanding, mathematical concepts, improvement of achievement scores [37], [38]. Additionally, the introduction of robotics in curriculum increases the interest of children in engineering [37]. According to [39], the use of robots in education allows children to engage in interactive learning activities. Robots also appear effective in language skill development [40].

4 Challenges and Potential Future Directions

The 21st century vision of education is based on innovation and world-level technology. It is known that around 15% of the general population has learning difficulties [41]. Research in the area of robotics have made evident numerous possibilities for further innovation in the education of children. Future research needs to deal with the more effective design of robots to align with the educational needs, in terms of hardware and software. Effective hardware design need to fulfil the following requirement: (1) low cost, in order to support the pedagogical model of one robot per student, (2) advanced design, so as to support a variety of interesting curricula e.g. many sensors for a broader range of applications and (3) usability, so as the robot to have a simple easy-to-explain design. Design is usually the last consideration when incorporating robots into an application. However, studies reveal that design make a difference on robots' perception, thus enhances children to be more engaged to the activity [42]. Due to the scarce of commercially available robot platforms for education, most research groups design their own robots. This is obvious from the bibliography, since most of the reported applications that use commercial educational robotics in real-world situations, utilize in the majority either Lego for regular education, NAO for special education, or their own featured robots. A future direction for researchers is to contribute by developing affordable technologies for enhancing the learning process. Effective software design for education is also a future challenge. Commercial robots need to support several development environments, allowing students and teachers to develop at an advanced level, starting from block programming to script. At that point, it is worthy to mention the luck of skillful teachers that feel confident near advanced technology. Investment in training educators, in addition to the purchase cost of robots, reinforces the need for investigative research to demonstrate the benefits of each approach to the use of robotics in education, guiding schools towards the effective use of the available robotic technology. Moreover, innovative teaching strategies and methodologies in terms of well-defined curriculum and learning material, transferable across the regions to support effective learning need to be developed. By creating game-like learning environments children in standard and special schools are more likely to reveal their creativity and potential.

Design of complex activities for a robot to perform, is highly probable to lead the robot to not being able to provide the guidance necessary to facilitate learning, due to technical limitations in current technology in terms of perception [14]. This invariably raises an obstacle, where the only solution is to wait that robots reach an adequate level of intelligence to play such roles. Research across the world attempts to give intelligence to social robots so that they can be used as assistants or teachers in education. In conclusion, further directions must be oriented to promote the application of robots in education, overcome the learning difficulties of children and raise the educational level of the future citizens, for a better quality of life and competence of a large number of people.

Social robots might call for an innovative modeling methodology due to their interaction with humans according to the following rationale. The operation of conventional (i.e. non-social) robots typically occurs in a physical environment excluding humans based solely on electronic sensors; hence, numerical models suffice. Nevertheless, when humans are involved non-numerical data emerge such as words. In the latter context, the Lattice Computing (LC) paradigm has been proposed for modeling based on numerical and/or non-numerical data in social robot applications [4]. It remains to experiment with alternative modeling paradigms toward confirming any advantages they might have in educational applications.

Social robots combined with ICT (Information and Communication Technologies) might be advantageous for delivering education in difficult landscapes especially in Balkan countries as explained in the following. In most Balkan countries, e.g. Bulgaria, there are extensive mountainous ranges. In other Balkan countries, including Greece and Croatia, in addition there are numerous inhabited islands. In all aforementioned countries there are dispersed communities living in small villages/towns, not easily accessed by conventional transportation. For all the latter communities social robots combined with ICT, e.g. the Internet, can imply cost-effective educational opportunities delivered locally [5].

Robots are considered to sustain a physical substance, therefore both code and hardware are subject to licensing. While manufacturing has been the biggest beneficiary of robots' recent wide use, it is common in recent years that robots enter the mainstream as well. Open-source robotics have enabled rapid development of previously expensive and sophisticated system within a lower budget and flatter learning curves for developers. There are many open-source projects that can help beginners to get started. A number of open-source hardware platforms (Sparki, Hexy, OpenPilot, Arduipilot, TurtleBot etc.) and open-source software projects (LeJOS, Rock, ROS etc.) exist and can support robotic research, education and product development.

5 Conclusions

This paper presents a literature review of commercial robots currently available in education. Its scope is to analyze and evaluate the effectiveness of commercial robots in education according to (1) design specifications and (2) to their reported results on educational applications in the last two years. Advantages and drawbacks for both approaches are presented. The aim of the review is to help researchers and teachers, to inform on recent robotics and their applications to education, in order to guide the way for potential future directions.

The commercial robots presented in this work are selected according to their application in the most recent reports of the bibliography regarding educational experimental researches, and according to the age to which these robots are addressed to, so as to cover a wide range of ages. It should be acknowledged that this study is based on seven selected commercial robotic platforms according to the aforementioned criteria. Other criteria and databases would have yielded more and different commercial robots and reference articles.

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