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Where does Arduino's power come from?: An extended literature review

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ABSTRACT

The aim of this literature review is to examine the applications and researches related to the use of Arduino boards in learning and teaching environments. The study conducted a content review of 100 studies published between the years 2006-2016 by using the indexes of Educational Research Information Center (ERIC), Academic Search Complete, Directory of Open Access Journals (DOAJ), IEEE/IEL, Science Direct, Scopus, ProQuest, Google Scholar and Web of Science. In-depth examination showed that that there were various approaches and practices in the case of using Arduino technology in literature. The fact that Arduino-based robot projects spread quickly and effectively was the first thing that this study found. Due to the contribution of Arduino technology to design and development process of educational robotics system, this study revealed that recent studies mostly focused on the efforts of integration and implementation of Arduino boards into educational activities and curriculums. This study listed the academic disciplines in which the studies used Arduino boards for learning and teaching activities and revealed the achievements with the application of Arduino boards. This study also determined the research methods and technological tools used in the prior research and reported the difficulties and problems related to the use of the Arduino boards.

Keywords: *Arduino, sensor, robotics, STEM, IoT*

INTRODUCTION

Arduino boards are small electronic circuits including AT-mega microcontroller and other electronic components. There are different types of Arduino boards that their functionality are same, but their size, pin numbers and Microprocessor capabilities are different. The basic idea behind the Arduino comes from the fact that it is open-source and available to everyone interested in developing new projects. Arduino IDE (integrated development environment) is also very easy to install, use, and develop new sketches based on the integrated examples. Arduino boards also support different types of shields by which anyone interested in developing new and large projects could use it easily.

Developed by 2005 from team Massimo Banzi, David Cuartielles, Tom Ingoe, Gianluca Martino and David Mellis in Italy, Arduino board's starting point was not education (Arduino, 2017). In electronics, especially for robotics system, the idea of DIY (do-it-yourself) developed rapidly with the introduction of Arduino. Later, researchers appreciated the freedom of Arduino boards and looked for new opportunities for their projects to create new ideas. Banzi (2008), as a co-founder of Arduino, published a book titled as "Getting Started with Arduino". In his book, Banzi explained the Arduino as

"The Arduino philosophy is based on making designs rather than talking about them. It is a constant search for faster and more powerful ways to build better prototypes. We have explored many prototyping techniques and developed ways of thinking with our hands."(p.5)

Limitations of the Arduino

On the other hand, some studies mentioned the limitations of the Arduino boards. For example, Scolnic (2015) argued that Arduino has traditional text-based programming language based on C++ and makes it hard to understand the structure of the programming of the Arduino for people who are in-experienced or new to Arduino. Other studies also argued that a well-designed visual programming might be easier to understand since Arduino sketches also include traditional code writing

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mentality (Blikstein, 2013; Lab Kits Using the Arduino Prototyping Platform, 2010). Another challenge comes from the fact that many researcher and institutions are trying to understand how to integrate Arduino more deeply in class environments, for K-12 (David, 2011).

Scolnic (2015) indicated that Arduino, normally, was not designed for educational purposes. The starting point of the Arduino was based on developing DIY electronic circuits for hobbyists and designers. Because of this, many researchers found it hard to implement Arduino based activities into class environment. Moreover, Arduino, for many high-level applications and projects, needs external programs and user-developed libraries by which users might develop further projects and expand the capabilities of the Arduino boards. Similarly, Linsalata (2012) indicates that Arduino boards, as integrated software and hardware environment, maintain high-level coding knowledge and wiring system thorough libraries for inputs and outputs that make it hard to combine basic functions together. Especially, high-level projects like Arduino robotics systems need abstraction of many different functions rather than simple processor operations.

Arduino based Robotics Technologies

The answer to question of "Why Arduino" lies beneath Arduino' flexible and user-friendly structure. It is very easy to distinguish Arduino boards from microcontroller due to its simple and accessible user experience. Arduino software and hardware is very understandable for beginners, yet flexible enough for advanced users, for example, thinking of getting started with robotics applications. In this sense, Hau-Shiue Juang, & Lum (2013), in their study, reported the design, construction and control of a two-wheel self-balancing robot. Results showed that self-balancing can be achieved with PI-PD control in the vicinity of the upright position. Arduino based structure allowed researchers to design improvement, low cost remote control, and obstacle avoidance and perimeter following. Karvinen & Karvinen (2011) showed how to build a robot that responded to electrical activity in brain. They used Arduino that had basic mechanical building skills. Their process mostly focused on how to construct a robot that plays sounds, blinks lights, and reacts to signals from an affordable head set. Similarly, Margolis (2012), in his book, showed building an Arduino based robot. In the book, Arduino made it easy to construct and build a program by which a robot could roam around. Moreover, Gargava, Sindwani, & Soman (2014), in their study, established an application to control a robot on the Arduino platform by the use of a BCI (brain control interface) system, which did not require training for individual users. They designed and developed BCI processing pipeline built on open-source platforms using the Emotiv EEG headset. Results showed that system achieved around 96% accuracy using computationally inexpensive feature extraction and classification techniques.

In this regard, some studies also focused on implementing Arduino based applications in educational programs. For example, Jooeun, Jooyoug& Jaechang (2014) performed a short-term computer information and communication technology education using Arduino. The purpose of the study was about practicing basic examples about H/W, S/W, communication, and solving creative tasks. The study showed that they developed meaningful ICT integrated curriculum that had high usefulness in a short period. Results showed that students completed 96% out of 10 creative Arduino tasks.

From an educational perspective, Busaidi(2012) also discussed that any student can reconstruct and start using it to understand his/her subject by setting up platform and the algorithm adopted in controlling the servos as well as reading from the sensors in Arduino. In the study, the Arduino board was utilized as a final controller for the servomotors as well as a Data Acquisition Card (DAC). Eguchi (2016), in her study, focused on Arduino Robot as a competition and robotics initiative. Study introduced a case of RoboCupJunior and the effectiveness of its practice for enhancing learning of STEM contents and skills for innovation and creativity among participating students. Similarly, Wong (2015), in his study, proposed a new Arduino-based mobile robotics kit design for class activities. The study discussed the mechanical design, electronic components and software developments method of the robotics kit. Results argued that new robotics kit, CPSKit, has several overwhelming features over existing K-12 educational robotics kits. Results showed that

CPSKit, as a 3D-printable Arduino-based mobile robot, has good features such as versatility, accessibility, cost, and capabilities such as odometry and wireless communication. The study furhet argued that CPSKit might be implemented in K-12 or university level as manufacturing 3D-print designs.

From a technological perspective, Timmis (2011) focused on developing an Arduino based GPS robot and sending the location of the robot to a micro SD card and logging it to a text file. Araujo, Portugal, Couceiro, & Rocha (2015) presented a solution for integrating Arduino-based robotic platforms in robotics operating system through the development of a robotics operating system driver. The study showed that Arduino presented an ideal platform for educational robotics. Elfasakhany, Yanez, Baylon, & Salgado (2011) designed, developed and implemented an Arduino based robot arm with enhanced control. The study showed that Arduino robot arm accurately accomplished simple tasks, such as light material handling. Another Arduino based Robotics application belongs to Balogh (2010). In his study, Balogh (2010) described a new controller board for a mobile robot based on Arduino platform. The study showed the analysis and design principles of the new board regarding Arduino. In addition, the study showed some illustration examples. Lopez-Rodriguez & Cuesta (2016) presented a low cost robot based on Arduino. This study showed the design of an open educational low cost modular and extendable mobile robot. Similarly, Hernández, Poot, Narváez, Llanes, & Chi (2010), in their study, developed a robot with the help of Arduino and +X-bee. The robot could be controlled with certain freedom and autonomy without using wires. Alexan, Osan, & Oniga (2012) also focused on developing a personal assistant robot designed by Arduino. The study concentrated on designing Arduino-based robot for disabled people, as its main purpose is to assist an elderly or disabled person.

Phal, Phal, & Jacob (2014), in their study, focused on design and development process of an Arduino-based speech-controlled mobile robot. Zisimatos, Liarokapis, Mavrogiannis, & Kyriakopoulos (2014), similar to Elfasakhany, A., Yanez, E., Baylon, K., &Salgado, R. (2011)' study, presented a series of design directions for the development of low-cost, light-weight, modular Arduino-based robot hands. The study showed that robotic hands could be used for various applications, indicating that capabilities of hands were highly efficient.

Zhao and Zhu (2013), in their study, introduced the design and implementation of an autonomous obstacle-avoiding robot car. Arduino based robot car gave good experimental effect to researchers. Kulkarni, Grama, Suresh, Krishna, Antony (2014), in a similar way, focused on developing four-wheeled surveillance robot by Arduino and Android APIs. The researchers showed that the possibilities with surveillance robot are endless. The designed robot provided a platform for further research into improving its capabilities. Furthermore, Volos, Kyprianidis, & Stouboulos (2013) presented autonomous mobile robot, a motion controller, based on the dynamical behavior of a known discrete chaotic system. The researcher preferred to use Arduino for developing the robot system, indicating that Arduino is probably the most commercial platform which is used in a great number of applications, especially in robotics. Prabha, Antony, Meena and Pandian (2014) designed an autonomous robot to sense environmental data such as temperature, humidity, and air quality, along with GPS coordinates and store them on the cloud. The researchers used Arduino microcontroller to control robot and Raspberry Pi to communicate with the cloud. Junior, Neto, Hernandez, Martins, Roger, & Guerra (2013), in their study, presented an Arduino-based low cost educational robotics kit. The researchers indicated that the purpose of the robot was to support the teachers in diversifying their studies using robotics kit.

For a different field, Patoliya, Mehta, & Patel (2015), in their study, designed and developed a robot to detect and prevent any damage and loss to human life in battlefield. The researchers argued that robot would serve as an appropriate tool to help military people and to prevent illegal activities. In a similar way, Sathiyanarayanan, Azharuddin, Kumar, & Khan (2014) also developed a robotics system for military purposes. They successfully built a prototype robot capable of being controlled using hand gestures. The study argued that developed robot could undertake missions like border control, surveillance and active combat.

Al-Sahib, & Azeez (2015), by using Arduino and Rasberyy Pi, developed Internet mobile robot. The researchers indicated that developed robot could be controlled from any place via the Internet. Pahuja & Kumar (2014), in their study, designed a robot, which could be controlled by Android mobile Apps. The researchers also indicated that designed robot along with quality and repeatability were unmatched. Wasif, Raza, Rasheed, Farooq, & Ali (2013) also focused on developing an Arduino based robotic control system. They discussed the control of unbalanced system by implementing an adaptive rendition of the classic PD control. Lim, Lee, Tewolde & Kwon (2014), also, developed an efficient way of deployment of ultrasonic sensors for low-cost mobile robots. They presented sensor deployment strategies and a navigation method of a mobile robot using an orientation sensor of a Smartphone. Study results showed possibility of developing a low-cost indoor robotics platform for college education and robotics research laboratories.

Generally, prior research shows that Arduino based microcontroller applications are very successful in robotics design, development and implementation. It is very clear that Arduino made it easy to develop robotics applications easily, yielding people to focus on open-source applications. This process also improved the platforms of the Arduino (Balogh, 2010). Table 1 shows recent studies dealing with Arduino based robotic design and development. In this sense, it can be seen clearly that some studies mainly focused on mind-controlled robotic applications using Arduino board (Gargava, Sindwani, & Soman, 2014; Karvinen, & Karvinen, 2011). On the other hand, other studies only concentrated on designing and developing process of educational robotics system by using Arduino (Hernández, Poot , Narváez, Llanes, & Chi, 2010; Juang & Lum, 2013; Busaidi, 2012; Balogh, 2010; Elfasakhany, Yanez, Baylon, & Salgado, 2011). From a different perspective, Das, Sadhu, Vyas, Konar, & Bhattacharyya (2015) showed a real-time cooperation between two robots while transporting a stick from starting positions to fixed goal positions. Some studies focus on controlling Arduino based robotics system by Android base APPs, which require Bluetooth remote connection (Kulkarni, Grama, Suresh, Krishna, Antony, 2014; Patoliya, Mehta, & Patel, 2015; Pahuja, & Kumar, 2014).

Table 1. Some of the recent studies focusing on robotic design and development based on Arduino

The study	Purpose	Platform	Example
Eguchi (2016)	STEM, Educational	Arduino	RoboCupJunior
Wong(2015)	STEM, educational, 3D-printable Arduino-based mobile robot kit with various capabilities	Arduino	CPSKit
Araujo, Portugal, Couceiro, &Rocha (2015)	Educational Mobile Robot	Arduino-based	TraxBot; TraxBot; StingBot/ROS driver
Gargava, Sindwani, & Soman (2014)	Brain control interface	BCI+ Arduino	Robot control with BCI
Hernández, Poot, Narváez, Llanes & Chi (2010)	Design and implementation of a Robotics system	LPT Interface/ Arduino + X-bee	Parallel port controlled robot
Juang & Lum (2013)	Design, construction and control of a robot	Arduino microcontroller board	Two-wheel self-balancing robot
Busaidi (2012)	Development of an educational environment for online control of robot	MATLAB+Arduino	Bioloid Biped robot
Balogh (2010)	Educational Robotic Platform	Arduino	Acrob(robot)

Elfasakhany, Yanez, Baylon, &Salgado (2011)	Design and development of a robotic arm	Labview+Arduino	Robotic arm applications
Alexan, Osan & Oniga (2012)	Robotic assistance to disabled persons	Arduino compatible board (CHIPKIT Max32) +Android	Assistive technology/robot
Karvinen, & Karvinen (2011)	Mind controlled robot	Arduino	Robot
Phal, Phal, & Jacob (2014)	Speech controlled robot	Arduino based	Robot
Zhao & Zhu (2013)	Design and implementation of an autonomous obstacle-avoiding robot car	Arduino based	Robot car
Zisimatos, Liarokapis, Mavrogiannis, & Kyriakopoulos (2014)	design and development of low-cost, light-weight, modular robot hands	Arduino based	Robotic hands
Kulkarni, Grama, Suresh, Krishna, Antony (2014)	Four-wheeled surveillance robot	Arduino+Android	Survillance robot
Volos, Kyprianidis, & Stouboulos (2013)	The design of an autonomous mobile robot, a motion controller, based on the dynamical behavior of a known discrete chaotic system	Arduino	Mobile robot
Prabha, Antony, Meena & Pandian (2014)	Autonomous robot to measure temperature, humidity, and air quality, along with GPS coordinates and store them on the cloud	Arduino+ Raspberry Pi	Robot
Das, Sadhu, Vyas, Konar, & Bhattacharyya (2015)	Two mobile robots carrying a stick to a destination	Arduino based+ X bee	Two robots avoiding obstacles
Junior, Neto, Hernandez, Martins, Roger, & Guerra (2013)	Educational robotics kit	Arduino based	Robot
Patoliya, Mehta, & Patel (2015)	War field spy robot using night vision wireless camera	Arduino+Android	Robot
Al-Sahib, & Azeez (2015)	Internet mobile robot	Arduino+ Raspberry Pi	Robot
Pahuja, & Kumar (2014)	Mobile Phone Controlled Bluetooth Robot	Arduino+Android	Robot
Wasif, Raza, Rasheed, Farooq, & Ali (2013)	Design and Implementation of a Two Wheel Self-Balancing Robot	Arduino based	Robot
Sathiyanarayanan, Azharuddin, Kumar, & Khan (2014)	Gesture Controlled Robot For Military Purpose	Arduino based	Robot
Lim, Lee, Tewolde, & Kwon (2014)	Use of Smartphone Sensors for Mobile Robot Navigation	Arduino based	Robot

Table 1 clearly shows that many recent studies describe their robot design process developed on Arduino platforms. It is clear to see that in robotic projects, researchers mostly prefer to use Arduino microcontroller. Arduino based technology allows researchers to support and motivate learning in design and development process of robot projects. The reason for that is economically feasible, taking in consideration its low cost. Secondly, due to open-source feature, Arduino based robotic projects give independence of suppliers of parts and components. On the other hand, other robotics kits such as Legos has only closed standard and proprietary components.

Literature review clearly shows that in design and development process of robotics systems using Arduino, integrating other software technologies into same project create new opportunities and directions for the Arduino based platforms. In this sense, Pahuja, & Kumar (2014), Patoliya, Mehta, & Patel (2015), and Kulkarni, Grama, Suresh, Krishna, Antony (2014) focused on creating a robotics system by using Arduino platform and Android API together. Especially, projects based on surveillance or military purposes, using Arduino with other technological tools seemed to be more implementable in real world applications (Figure 1).

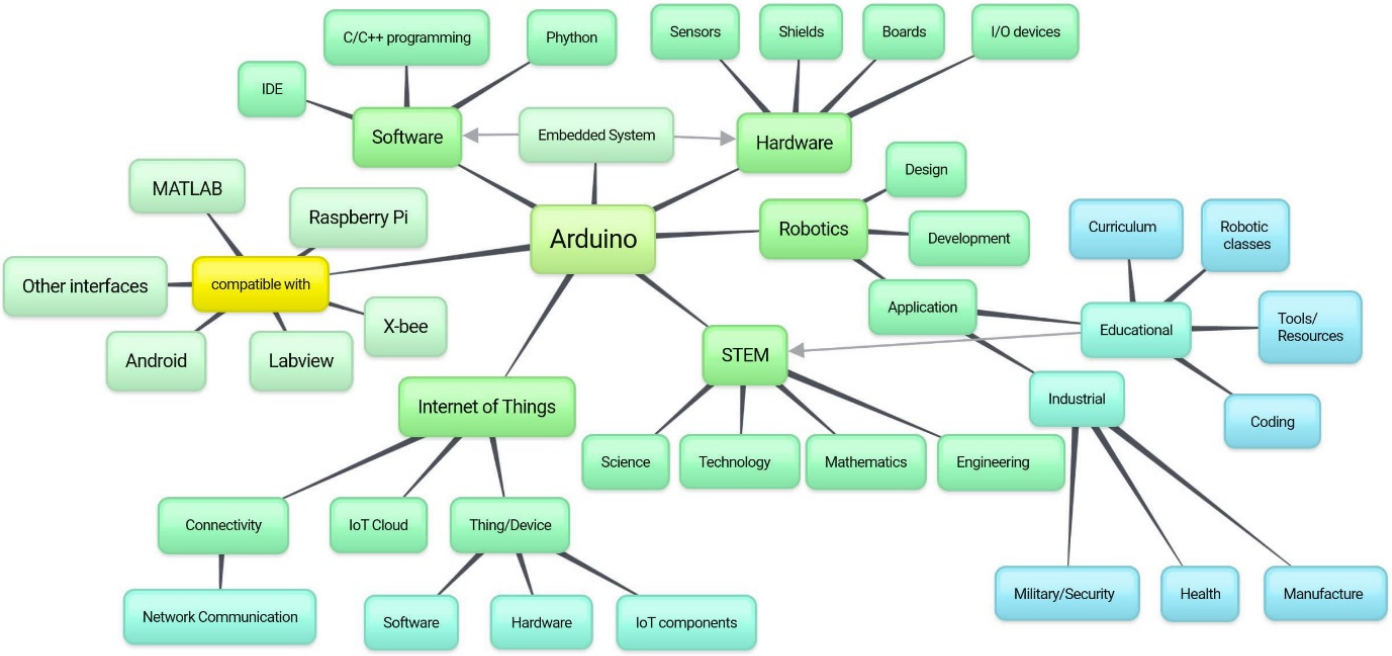


Figure 1. A content map regarding Arduino technology

Arduino in educational field

It would be a good idea to relate Arduino experiences in teaching and learning process while providing the students access to the Arduino platform and its open source community. Thus, this study intended to investigate Arduino in course environments and tried to show how the Arduino can be used to expose the students to many of the topics normally included in educational programs. For example, Jamieson (2010) described a project based learning embedded system course. Study results showed that using the Arduino exposed students to sufficient complexity and challenges for an embedded system course. From a different perspective, García-Peñalvo, Rees, Hughes, Jormanainen, Toivonen, & Vermeersch (2016), in their study, presented the most popular robotics products in order to help teachers to introduce programming in pre-university studies. In this sense, many products like Robbo and mBot are built with Arduino microcontrollers. Arduino-based Robots have LED, sensors and motors to move the robots around. In this way, students can get easily involved in programming and coding process. Similarly, Grover, Krishnan, Shoup, and Khanbaghi (2014) investigated an undergraduate mechatronics course using the Arduino platform. The study showed very encouraging results and

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indicated Arduino-based course provided effective learning environment for undergraduate students. Kapur, Hochenbaum, Darling, Diakopoulos, Trimpin (2011) focused on the technical details of the Arduino-based NotomotoN, a musical robotic system, and discussed its use in performance and educational scenarios. The study results showed that NotomotoN served as a means by which students could rapidly test new beater designs. Gartseev, Lee, and Krovi (2011) created ArEduBot, an Arduino-based low-cost realtime mobile-robot platform. The study discussed the educational aspects of the ArEduBot in introductory robotics and mechatronics classes to complement the lecture and to support project-based learning. Rahul, Whitchurch, and Rao (2014) introduced a graphical approach to programming in an undergraudate level coursr. The programming utility was basically developed for an open source Arduino platform. The results showed that students found to be easy to learn by programming tool with the robotic hardware. Candelas, García, Puente, Pomares, Jara, Pérez, Mira, & Torres (2015), in their study, described using Arduino platform in different laboratory experiments of engineering courses. Furthermore, the study results showed that Arduino based laboratory experiments increased students' interest verified by academic results and surveys.

Table 2. Some recent studies implementing Arduino in class environments

The study	Field	Approach
Jamieson (2010)	Computer Science/Engineering	Project-based learning with Arduino
García-Peñalvo, Rees, Hughes, Jormanainen, Toivonen, & Vermeersch (2016)	Programming/ Pre-university level	Tools/resources regarding Arduino
Grover, Krishnan, Shoup, and Khanbaghi (2014)	Undergraduate mechatronics course	Robotics course curriculum/classroom teaching Arduino based platform
Androutsopoulos, Gorogiannis, Loomes, Margolis, Primiero, Raimondi, Varsani, Weldin, & Zivanovic (2014)	First year Computer Science	Attendance/engagement/progression (A racket-based robot)
Kapur, Hochenbaum, Darling, Diakopoulos, Trimpin (2011)	Musical classes/ musical robotic education curriculum	New learning strategies
Gartseev, Lee, and Krovi (2011)	Robotics & Mechatronics class	Complementing the lecture and supporting project-based learning.
Rahul, Whitchurch, and Rao (2014)	Introductory programming curriculum for undergraduates	Visual learning
Kuan, Tseng, Sufen, & Wong (2016)	Physics	Students' confidence and motivation
Qiu, Buechley, Baafi, & Dubow (2013)	Computer Science/programming	Successful implementation of the curriculum
Albrecht, Bender, & Kussmann (2012)	Computer Science	n/a
Candelas, García, Puente, Pomares, Jara, Pérez, Mira, & Torres (2015)	Engineering Courses/ Automatic Control and Robotics course	Laboratory experiments

Prior research clearly shows that compared to other microcontrollers and microcontroller platforms such as Parallax Basic Stamp, Netmedia's BX-24, Phidgets, MIT's Handyboard, Arduino presents some unique features that make it preferable for educational purposes. The prominent feature of the Arduino boards is their cost. Secondly, many microcontroller platforms only runs on Windows.

However, Arduino boards runs on Windows, Macintosh OSX and Linux operating systems. In this way, everyone can use Arduino boards according to their needs. Moreover, Arduino offers an open-source platform for everyone. With this feature, even unexperienced users can develop different modules, programs and boards by which order-based projects and programs are easily developed. In this sense,

Androutsopoulos, Gorogiannis, Loomes, Margolis, Primiero, Raimondi, Varsani, Weldin, & Zivanovic (2014), in their study, described Arduino-based open-source robot platform to support teaching of core Computer Science topics. The study presented teaching and assessment strageis, as well as evaluation of their teaching approach. Kuan, Tseng, Sufen, & Wong (2016) proposed an Arduino-based integrated curriculum for the freshmen of a physics department. Results showed that the curriculum helped students gain knowledge of programming and instrumentation, and increased the students' confidence and motivation to learn physics and computer languages.

Qiu, Buechley, Baafi, & Dubow (2013) presented a curriculum teaching computer science and computer programming. The study results clearly showed that curriculum increased students' comfort with, enjoyment of, and interest in working with electronics and programming. In a similar way, Albrecht, Bender, & Kussmann (2012) proposed an Arduino based curriculum in undergraduate computer science course. The researchers argued that the Arduino platform would bring a new direction and attract new students into program.

There are also opposite views and research regarding the implementation of Arduino boards into class curriculum and activities. For example, Linsalata (2012) argues that although Arduino boards are favorable for educational purposes, there are still some limitations to use Arduino boards in educational environments. The most noticeable deficiency is Arduino' programming language. Since Arduino uses C/C++ programming language and environment, every sketch of Arduino must rely on C/C++ coding and compiling to generate a working code system. This brings another problem that since all Arduino boards are similar to each other, Arduino programming environment works only by using C/C++ programming environments and passing to code sketches to a compiler. In this sense, the Arduino compiler only sends low-level coding sketches to compiler, meaning that high-level coding knowledge and programming needs some kind of expertise to produce advanced projects. Linsalata (2012) further argues that Arduino boards only use similar microprocessors within the same chip family (Atmega 128 etc.). This feature limits to use different chip architecture, meaning that allows developing different projects and ideas. Arduino' similar microprocessor structure allows users to develop projects with simple differences by defining same functions.

Arduino and STEM education

Research on using Arduino boards in STEM education has two folds. One approach focuses on only design, development and implementation process of a robotics system (Hernández, Poot, Narváez, Llanes & Chi, 2010; Juang & Lum, 2013; Busaidi, 2012; Elfasakhany, Yanez, Baylon &Salgado, 2011; Zhao & Zhu, 2013; Zisimatos, Liarokapis, Mavrogiannis, & Kyriakopoulos, 2014; Volos, Kyprianidis, & Stouboulos, 2013; Wasif, Raza, Rasheed, Farooq, & Ali, 2013). This kind of research mainly tires to focus on robotics design in terms of engineering perspective and handle the robotics system as control and design of developed robots. Brain control robots, mind controlled robots, speech controlled robots, surveillance robots are some examples of this kind. Fields like Military, Surveillance are other good examples for this kind approach. Developing robotic systems seem more important than teaching or learning with robotics systems. However, as a second approach, some studies directly focused on implementing robotics system in class environments (Jamieson, 2010; García-Peñalvo, Rees, Hughes, Jormanainen, Toivonen, & Vermeersch, 2016; Grover, Krishnan, Shoup, and Khanbaghi, 2014; Androutsopoulos, Gorogiannis, Loomes, Margolis, Primiero, Raimondi, Varsani, Weldin, & Zivanovic, 2014; Kapur, Hochenbaum, Darling, Diakopoulos, Trimpin; 2011; Gartseev, Lee, and Krovi, 2011; Rahul, Whitchurch, and Rao, 2014; Kuan, Tseng, Sufen, & Wong, 2016; Qiu, Buechley, Baafi, & Dubow, 2013; Albrecht, Bender, & Kussmann, 2012). In this regard, for specific college courses and curriculums, schools

began to use robotics systems to teach topics not necessarily relate to robotics technology (Wong, 2015). Some college level courses use Arduino based robotics system to teach subjects such as Computer Science/Engineering, pre-university level programming, mechatronics and physics courses.

Hoffer (2012), in his study, argued that Arduino boards and their open source nature make it ideal platform for STEM (Science, Tecnology, Engineering, and Matematics) education. Faugel, & Bobkov (2013), in their study, argue that IDE environment of the Arduino provides a large number of libraries easing the implementation of standard applications such as using sensors or I/O devices. Moreover, the price of the Arduino boards is reasonably low and affordable by many students and the software development process by IDE is free in Arduino boards. Thus, the students and teachers freely can download the IDE of the Arduino in website and use it to develop their own projects in STEM education. Moreover, there are a variety of web sites and educational blogs to further education and expand the capabilities of the Arduino boards. However, as an opposite view, Hayward (2016), also, focused on definition of I-STEM (Integrated STEM education) in his study, in terms of teachers' point of view, indicating factors that support I-STEM lessons. The study results clearly showed that there was a lack of consistency among I-STEM disciplines, including Engineering Courses, PLTW Courses, Python/Arduino Sketch and Technology of Robotic Design.

Eguchi (2016), in her study, introduced a robotics system to enhance students' learning in STEM contents and skills for innovation and creativity. The study results argued that Arduino based educational robotics systems, generally, increase students' interest and motivation. Especially, the study showed that robotics competition activities provided long-lasting impacts for STEM subjects. In a similar way, Wong (2015), in his study, argued that robotics systems used in class activities might be the dominant effect on science and technology. Nature of designing robotics system allows handling many interdisciplinary areas in STEM fields. In sum, prior research mostly shows that Arduino based robotics activities help students keep engaged in STEM education.

Arduino and IoT (Internet of Things)

According to Wortmann, & Flüchter (2015), the definition of IoT is very broad and there is no common consensus on what IoT technologies actually include. Prior research clearly shows that IoT technologies mainly were based on RFID (radio-frequency identification) infrastructures (Doukas, 2012; Xia, F., Yang, L. T., Wang, L., & Vinel, 2012). Since then, general definitions of IoT emphasis the things that become connected with Internet. Internet protocols and network technology seemed important components in IoT technologies. In addition to these definitions, Atzori, Iera, & Morabito (2010) added cloud technologies (data management, process management and thing/device communication and management) to the definition of IoT. Based on prior research, it can be concluded that applications of IoT technologies are very broad and continuing to extend nowadays.

The basic idea behind IoT is the network that connects physical devices (things) with Cloud technologies, Internet/web applications and network communications (Doukas, 2012). In this sense, IoT based devices allows users to access, store and retrieve data on the Internet and interact with other physical devices (Xia, Yang, Wang, & Vinel, 2012). Therefore, in order to create IoT based devices and applications, users need to use platforms allowing remote controls and data management systems. Doukas (2012) argues that Arduino boards are one of the suitable examples for IoT technologies. Arduino boards have IDE environment easy to understand and use, and micro-controllers allowing controlling different sensors and many Arduino shields. For this reason, the idea of "open-source" mentality of Arduino boards fits very well with IoT platforms, which Arduino boards offer simple, functional and extendable features for wired and wireless projects. In this regard, Al-Fuqaha, Guizani, Mohammadi, Aledhari, & Ayyash (2015), in their study, indicate that IoT elements include following components: identification, sensing, communication, computation, services, and semantic. The study clearly argued that Arduino (among other platforms such as TinyOS, Contiki, LiteOS, RiotOS) was one of the most common operating systems used in IoT environments.

IoT based research in literature review mostly seems to focus on home control and monitoring systems. For example, Piyare (2013) presented a home control and monitoring system remotely using Arduino based technology. The study argued that IoT based system was feasible and effective in terms of controlling devices in home environment. Similarly, Soliman, Abiodun, Hamouda, Zhou, & Lung (2013) focused on creating smart home system in which home appliances and settings were controlled by IoT based technology. The study used embedding intelligence into sensors using Arduino board. Sundmaeker, Guillemin, Friess, & Woelfflé (2010), in their book, described Arduino as one of the specific IoT products that have indeed gained visibility recently. Barbon, Margolis, Palumbo, Raimondi, & Weldin (2016) presented an Arduino based IoT system including service interface programming model in which provided support to network boards using different strategies.

Research clearly shows that Arduino boards play an important role in developing IoT based technologies. Arduino provides an open-source implementation of the code running on Arduino boards and in this way, users create flexible and functional wired or wireless projects according to their needs (Wortmann, & Flüchter, 2015; Xia, Yang, Wang, & Vinel, 2012; Sundmaeker, Guillemin, Friess, & Woelfflé, 2010; Soliman, M., Abiodun, T., Hamouda, T., Zhou, J., & Lung, 2013; Piyare, 2013; Doukas, 2012; Barbon, Margolis, Palumbo, Raimondi, & Weldin, 2016; Atzori, Iera, & Morabito, 2010; Al-Fuqaha, Guizani, Mohammadi, Aledhari, & Ayyash, 2015). Galadima (2014), in his study, presented applications to be taken as examples that can help make learning Arduino more interesting. The study argued that these examples encourage students and teachers to learn more about electronics and programming.

CONCLUSION AND FUTURE REMARKS

This paper presented an extended literature review regarding Arduino technology, in terms of its low cost and flexible system using an embedded microcontroller, with STEM, IoT and Maker movement aspects including coding teaching and prototyping. This study clearly, and in detail, shows the strength and popularity of the Arduino boards with respect to similar systems and explains the studies focusing on the design, development and implementation process of Arduino based robotics systems. This study argues that Arduino boards offers a suitable environment to create both wired and wireless projects using different communication protocols and monitoring and controlling different IoT technologies. Prior research argues that Arduino based projects are easy to be extended and applied to different situations since Arduino has ability to support different sensors and shields showing the feasibility and effectiveness of Arduino based systems (Xia, Yang, Wang, & Vinel, 2012; Sundmaeker, Guillemin, Friess, & Woelfflé, 2010; Piyare, 2013).

For the purpose of this study, 100 studies(research articles, proceedings, books, dissertations) mainly focusing on Arduino boards and their relation to robotics systems, education, STEM, IoT, Maker and prototyping were investigated deeply to make a clear understanding on how prior research shaped around Arduino technology and to which direction research focus have gone so far. This study found that Arduino technology and compatible products have an overwhelming superiority over other systems. This superiority comes from the fact that Arduino boards use open-source microcontroller technology and IDE environment allowing everyone to contribute and customize it. Thus, Arduino based projects seem to widespread into many disciplines and influence many people from different fields.

Secondly, this study found that Arduino based robotics systems are very common in researchers. Moreover, it is clear from prior research that Arduino based robotics systems enhances students and teachers' point of view and catches their attention toward educational robotics and promotes STEM interests among students. This study clearly found that Arduino technology allows student and teachers to develop project-based and goal-oriented activities regarding STEM related fields. Many schools and educational institutions began to integrate embedded systems like Arduino into their curriculum and class activities. Research results generally shows that Arduino based activities have long-lasting impact on students' understanding of STEM fields. Computer Science/Engineering courses, pre-university level

programming courses, undergraduate mechatronics courses, Musical classes, and Physics are some examples in which Arduino technology was successfully integrated into curriculum and classes.

This study highlighted four cases of technological contributions made by Arduino systems: (1) Arduino based Robotics technologies (2) Arduino in educational field (3) Arduino and STEM education (4) Arduino and IoT (Internet of Things). What was presented in this study was related to contributions made by Arduino technology to different fields in general. For example, IoT technologies, STEM and robotics systems seem to be effected and benefited from Arduino's open source mentality and Maker Movement of Arduino (Barbon, Margolis, Palumbo, Raimondi, & Weldin, 2016; Hayward, 2016; Hoffer, 2012; Soliman, Abiodun, Hamouda, Zhou, & Lung, 2013; Xia, Yang, Wang, & Vinel, 2012).

Opposite views also exits in literature review (Scolnic, 2015; Blikstein, 2013; Lab Kits Using the Arduino Prototyping Platform, 2010; David, 2011; Linsalata, 2012. Firstly, there is a lack of collaboration and consensus on how to implement Arduino based technologies in educational organizations, and schools interested in promoting Arduino in their environments. This study argues that Arduino based technologies provides valuable impacts on educational field, as explained in Table 2, by experiencing and advancing new technological opportunities among students, teachers and researchers. Secondly, Arduino boards have some technical limitations. For example, when it is necessary to make and use the circuits permanently, the difficulties of conventional circuit production are more visible in Arduino circuits. Moreover, initial Arduino cards are economical; however, the cost for the advanced Arduino boards and shields are increasing dramatically. This can be considered as a hidden disadvantage for Arduino boards. In addition, the input/output ports on some boards like UNO are limited. Many middle-level and advanced projects and applications inevitably push users to use different Arduino boards, which lead to a change in cost.

This research clearly shows that IoT technologies are getting popular and expectations are rising. In this regard, Arduino technology seems to contribute in communication and network and manage things/devices in IoT technologies. In addition, this study argues that Arduino technology plays a dominant role in providing embedded sensors, actuators, processors, and other physical devices to IoT based projects. This study also argues that more research is needed to investigate how the implementation of Arduino platforms suit with integration of information and communication technologies in IoT applications. Thus, the idea of open source mentality and effectiveness of Arduino boards might be deeply investigated and adapted to create new design, development and implementation of IoT technologies. To better control for risky factors and to identify any technology based problems regarding Arduino boards, future studies should investigate different embedded platforms to compare and contrast features and identify and address experiences regarding using embedded platforms in robotic system as well as in IoT technologies. Moreover, from an educational point of view, implementation of Arduino based technologies require more concrete evidence by which educators will be eager to integrate hardware and software features of Arduino boards in class activities. This study presented some research regarding using Arduino in curriculum and class activities; however, prior research shows that there is lack of focus and harmonization with regard to applying Arduino bases technologies into class environments. Also, Arduino based STEM activities and Maker movements need some kind of standardization and alignment as well as the integration of the embedded hardware and software domains to enhance student learning and teacher awareness and productivity representing further important challenges in the development of Arduino based technologies.

REFERENCES

Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). Internet of things: A survey on enabling technologies, protocols, and applications. *IEEE Communications Surveys & Tutorials*, *17*(4), 2347-2376.

Albrecht, W., Bender, P., & Kussmann, K. (2012). Integrating microcontrollers in undergraduate curriculum. *Journal of Computing Sciences in Colleges*, *27*(4), 45-52.

Alexan, A. I., Osan, A.R., & Oniga, S. (2012). *Personal assistant robot. 18th International Symposium for Design and Technology in Electronic Packaging (SIITME)*, 25-28 Oct. 2012 (DOI: 10.1109/SIITME.2012.6384348).

Al-Sahib, N. K. A., & Azeez, M. Z. (2015). Build and Interface Internet Mobile Robot using Raspberry Pi and Arduino. *Innovative Systems Design and Engineering*, *6*(1), 106-114.

Androutsopoulos, K., Gorogiannis, N., Loomes, M., Margolis, M., Primiero, G., Raimondi, F., Varsani, P., Weldin, N., & Zivanovic, A. (2014, May). A racket-based robot to teach first-year computer science. *In 7th European Lisp Symposium* (p. 54).

Araujo, A., Portugal, D., Couceiro, M.S., &Rocha, R. P. (2015). Integrating Arduino-Based Educational Mobile Robots in ROS. *Journal of Intelligent & Robotic Systems, 77*(2), 281-298.

Arduino (2017). *Credits.* Retrieved 18.10.2107 from https://www.arduino.cc/en/Main/Credits

Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: A survey. *Computer networks*, *54*(15), 2787-2805.

Balogh, R. (2010). Educational robotic platform based on Arduino. *Proceedings of the 1st international conference on Robotics in Education, RiE2010*. FEI STU

Banzi, M. (2008). *Getting Started with Arduino*, Make: Books, CA: USA.

Barbon, G., Margolis, M., Palumbo, F., Raimondi, F., & Weldin, N. (2016). Taking Arduino to the Internet of Things: the ASIP programming model. *Computer Communications*, *89*, 128-140.

Blikstein, P. (2013). Gears of our childhood: constructionist toolkits, robotics, and physical computing, past and future. *Proceedings of the 12th International Conference on Interaction Design and Children*, 173–182.

Busaidi, A. M. (2012). Development of an educational environment for online control of a biped robot using MATLAB and Arduino. *Mechatronics (MECATRONICS) Mecatronics-REM, November 21-23, 2012, Paris, France* (DOI: 10.1109/MECATRONICS.2012.6451030)

Candelas, F. A., García, G. J., Puente, S., Pomares, J., Jara, C. A., Pérez, J., Mira, D., & Torres, F. (2015). Experiences on using Arduino for laboratory experiments of Automatic Control and Robotics. *IFAC-PapersOnLine*, *48*(29), 105-110.

Das, P., Sadhu, A. K., Vyas, R. R., Konar, A., & Bhattacharyya, D. (2015, February). Arduino based multi-robot stick carrying by Artificial Bee Colony optimization algorithm. In *Computer, Communication, Control and Information Technology (C3IT), 2015 Third International Conference on* (pp. 1-6). IEEE.

David K. (2011). *The making of arduino*, October 2011. Received 10.12.2017 at https://spectrum.ieee.org/geek-life/hands-on/the-making-of-arduino

Doukas, C. (2012). *Building Internet of Things with the ARDUINO*. CreateSpace Independent Publishing Platform.

Eguchi, A. (2016). RoboCupJunior for promoting STEM education, 21st century skills, and technological advancement through robotics competition. *Robotics and Autonomous Systems* 75/B, 692-699.

Elfasakhany, A., Yanez, E., Baylon, K., & Salgado, R. (2011). Design and Development of a Competitive Low-Cost Robot. *Modern Mechanical Engineering*, *1*, 47-55.

Faugel, H., & Bobkov, V. (2013). Open source hard-and software: Using Arduino boards to keep old hardware running. *Fusion Engineering and Design*, *88*(6), 1276-1279.

Galadima, A. A. (2014, September). Arduino as a learning tool. In *Electronics, Computer and Computation (ICECCO), 2014 11th International Conference on* (pp. 1-4). IEEE.

Gargava, P., Sindwani, K., & Soman, S. (2014). Controlling an arduino robot using Brain Computer Interface. *Proceedings of 3rd International Conference on Reliability, Infocom Technologies and Optimization, 8-10 Oct. 2014, Noida, India.* (DOI: 10.1109/ICRITO.2014.7014713)

Juang, H., & Lum, K. (2013). Design and Control of a Two-Wheel Self-Balancing Robot using the Arduino Microcontroller Board. *10th IEEE International Conference on Control and Automation (ICCA) (pp.634-639)*, Hangzhou, China, June 12-14, 2013.

Hayward, J. B. (2016). An analysis of secondary integrated STEM lesson plans: Common characteristics, learning expectations and the impact from the teacher's definition of I-STEM (Order No. 10249253). Available from ProQuest Dissertations & Theses

Global. (1850983195). Retrieved from https://search.proquest.com/docview/1850983195?accountid=11054

Hernández, C., Poot R., Narváez, L., Llanes, E., & Chi, V. (2010). Design and Implementation of a System for Wireless Control of a Robot. *International Journal of Computer Science Issues*, *7*(5), 191-197.

Hoffer, B. M. (2012). *Satisfying STEM education using the arduino microprocessor in C programming (Order No. 1520533).* Available from ProQuest Dissertations & Theses Global. (1069255002). Retrieved from https://search.proquest.com/docview/1069255002?accountid=11054

Jamieson, P. (2010). *Arduino for teaching embedded systems. Are computer scientists and engineering educators missing the boat?* Revised 10.9.217 at http://citeseerx.ist.psu.edu/viewdoc/summary?doi =10.1.1.217.7157

Jooeun, S., Jooyoug, K., & Jaechang, S. (2014). A Study on Training Courses Development and Analysis for Improving the Creativity using Arduino. *Journal of Korea Multimedia Society*, *17*(4), 514-525.

Junior, L. A., Neto, O. T., Hernandez, M. F., Martins, P. S., Roger, L. L., & Guerra, F. A. (2013). A low-cost and simple arduino-based educational robotics kit. *Cyber Journals: Multidisciplinary Journals in Science and Technology, Journal of Selected Areas in Robotics and Control (JSRC), December edition, 3*(12), 1-7.

García-Peñalvo, F. J., Rees, A. M., Hughes, J., Jormanainen, I., Toivonen, T., & Vermeersch, J. (2016). A survey of resources for introducing coding into schools. In F. J. García-Peñalvo (Ed.), *Proceedings of the Fourth International Conference on Technological Ecosystems for Enhancing Multiculturality (TEEM'16) (Salamanca, Spain, November 2-4, 2016)* (pp. 19-26). New York, NY, USA: ACM.

Gartseev, I. B., Lee, L. F., & Krovi, V. N. (2011, September). A low-cost real-time mobile robot platform (ArEduBot) to support project-based learning in robotics & mechatronics. In Proceedings of 2nd International Conference on Robotics in Education (RiE 2011) (pp. 117-124).

Grover, R., Krishnan, S., Shoup, T.,& Khanbaghi M. A.(2014). Competition-Based Approach for Undergraduate Mechatronics Education Using the Arduino Platform. *Interdisciplinary Engineering Design Education Conference (IEDEC) (*DOI: 10.1109/IEDEC.2014.6784685)

Kapur, A., Hochenbaum, J., Darling, M., Diakopoulos, D., Trimpin, J. M. (2011). The KarmetiK NotomotoN: A New Breed of Musical Robot for Teaching and Performance. *Proceedings of the International Conference on New Interfaces for Musical Expression*, 30 May - 1 June 2011, Oslo, Norway

Karvinen, T., & Karvinen, K. (2011). *Make a Mind-Controlled Arduino Robot: Use Your Brain as a Remote*. Oreilly, Tokyo.

Kuan, W., Tseng, C., Sufen, C., Wong, C. (2016). Development of a Computer-Assisted Instrumentation Curriculum for Physics Students: Using LabVIEW and Arduino Platform. *Journal of Science Education and Technology*, *25*(3), 427–438.

Kulkarni, C., Grama, S., Suresh, P. G., Krishna, C., & Antony, J. (2014, April). Surveillance Robot Using Arduino Microcontroller, Android APIs and the Internet. In 2014 *Proceedings of 2014 First International Conference on Systems Informatics, Modelling and Simulation.*

Lab Kits Using the Arduino Prototyping Platform **(**2010). *American Society for Engineering Education.*

Lim, J., Lee, S. J., Tewolde, G., & Kwon, J. (2014, June). Ultrasonic-sensor deployment strategies and use of smartphone sensors for mobile robot navigation in indoor environment. In *Electro/Information Technology (EIT), 2014 IEEE International Conference on* (pp. 593-598). IEEE.

Linsalata, R. S. (2012). Development of a universal robotics API for increased classroom collaboration within robotics education (Order No. 1512750). Available from ProQuest Dissertations & Theses Global. (1023453761). Retrieved from https://search.proquest.com/docview/1023453761?accountid=11054

Lopez-Rodriguez, F. M., & Cuesta, F. (2016). Andruino-A1: Low-Cost Educational Mobile Robot Based on Android and Arduino. Journal of Intelligent & Robotic Systems, *81*, 63–76

Margolis, M. (2012). *Make an Arduino-controlled robot*. O'Reilly Media, USA.

Pahuja, R., & Kumar, N. (2014). Android Mobile Phone Controlled Bluetooth Robot Using 8051 Microcontroller. *International Journal of Scientific Engineering and Research*, *2*(7), 14-17.

Patoliya, J., Mehta, H., & Patel, H. (2015, November). Arduino controlled war field spy robot using night vision wireless camera and Android application. In *Engineering (NUiCONE), 2015 5th Nirma University International Conference on* (pp. 1-5). IEEE.

Phal, D. D., Phal, K. D., & Jacob, S. (2014, December). Design, implementation and reliability estimation of speech-controlled mobile robot. In Emerging Technology Trends in Electronics, Communication and Networking (ET2ECN), 2014 2nd International Conference on (pp. 1-6). IEEE.

Piyare, R. (2013). Internet of things: ubiquitous home control and monitoring system using android based smart phone. *International Journal of Internet of Things*, *2*(1), 5-11.

Prabha, S. S., Antony, A. J. P., Meena, M. J., & Pandian, S. R. (2014, April). Smart cloud robot using raspberry Pi. In Recent Trends in Information Technology (ICRTIT), *2014 International Conference on (pp. 1-5)*. IEEE.

Rahul, R., Whitchurch, A., & Rao, M. (2014, December). An open source graphical robot programming environment in introductory programming curriculum for undergraduates. In MOOC, Innovation and Technology in Education (MITE), 2014 IEEE International Conference on (pp. 96-100). IEEE.

Qiu, K., Buechley, L., Baafi, E., & Dubow, W. (2013, June). A curriculum for teaching computer science through computational textiles. *In Proceedings of the 12th International Conference on Interaction Design and Children (pp. 20-27)*. ACM.

Sathiyanarayanan, M., Azharuddin, S., Kumar, S., & Khan, G. (2014). Gesture Controlled Robot for Military Purpose. *International Journal for Technological Research in Engineering*, *1*(11), 1300-1303.

Scolnic, J. (2015). Design, development and analysis of the EVDuino robotics prototyping platform (Order No. 1589510). Available from ProQuest Dissertations & Theses Global. (1705857868). Retrieved from https://search.proquest.com/docview/1705857868?accountid=11054

Soliman, M., Abiodun, T., Hamouda, T., Zhou, J., & Lung, C. H. (2013, December). Smart home: Integrating internet of things with web services and cloud computing. In *Cloud Computing Technology and Science (CloudCom), 2013 IEEE 5th International Conference on* (Vol. 2, pp. 317-320). IEEE.

Sundmaeker, H., Guillemin, P., Friess, P., & Woelfflé, S. (2010). Vision and challenges for realising the Internet of Things. *Cluster of European Research Projects on the Internet of Things, European Commision*, *3*(3), 34-36.

Timmis, H. (2011). Robot Integration Engineering a GPS Module with the Arduino. In: *Practical Arduino Engineering*, Apress Retrieved at 28.12.2017 from https://doi.org/10.1007/978-1-4302-3886-7_5)

Volos, C. K., Kyprianidis, I. M., & Stouboulos, I. N. (2013). Experimental investigation on coverage performance of a chaotic autonomous mobile robot. *Robotics and Autonomous Systems*, *61*(12), 1314-1322.

Wasif, A., Raza, D., Rasheed, W., Farooq, Z., & Ali, S. Q. (2013, September). Design and implementation of a two-wheel self-balancing robot with a two level adaptive control. In *Digital Information Management (ICDIM), 2013 Eighth International Conference on* (pp. 187-193). IEEE.

Wong, N. K. (2015). *Affordable open-source mobile robot kit for education and research (Order No. 10036057)*. Available from ProQuest Dissertations & Theses Global. (1774020355). Retrieved from https://search.proquest.com/docview/1774020355?accountid=11054

Wortmann, F., & Flüchter, K. (2015). Internet of things. *Business & Information Systems Engineering*, *57*(3), 221-224.

Xia, F., Yang, L. T., Wang, L., & Vinel, A. (2012). Internet of things. *International Journal of Communication Systems*, *25*(9), 1101.

Zhao, J., & Zhu, S. C. (2013). Design of Obstacle Avoidance Robot Car Based on Arduino Microcontroller [J]. *Automation & Instrumentation*, *5*, 002.

Zisimatos, A. G., Liarokapis, M. V., Mavrogiannis, C. I., & Kyriakopoulos, K. J. (2014, September). Open-source, affordable, modular, light-weight, underactuated robot hands. In Intelligent Robots and Systems (IROS 2014), 2014 IEEE/RSJ International Conference on (pp. 3207-3212). IEEE.