Developing a Concept of Available Multi-Functional Modular Robot for Education and Research

Oksana Mezentceva
28mos05@mail.ru

Vecheslav Petrenko
vip.petrenko@gmail.com

Fariza Tebueva
fariza.teb@gmail.com

Andrey Pavlov
losde5530@gmail.com

Artem Apurin
apurin.a@icloud.com

North Caucasus Federal University, Stavropol, 355009, Russian Federation

Abstract

The development of educational robotics is caused by the need to develop algorithmic thinking of students and the training of specialists in the technical direction. A number of robotic construction sets and platforms designed to form the competencies for solving complex engineering problems have been developed to ensure the educational process. These tools in educational robotics demonstrate high efficiency however the possibility of acquiring such a kit is limited by both the high cost of the proposal and the lack of ready-made experimental developments on the market. On this basis, the goal of this work is to improve the quality of education in robotics and programming by developing the concept of an affordable multifunctional modular robot based on small spherical robots. The ideas of both design solutions and the software component of the robot control system are proposed in the article. The analysis of the cost of components required for the implementation of the prototype. The advantages, disadvantages and limitations of the proposed solution are analyzed, and the potential applications of the modular robot are investigated. The expected results of the implementation of the proposed solution in the educational process are presented.

Keywords: educational robotics, modular robotics, robotics in higher education, innovate education.

1 Introduction

The introduction of robotics into education is becoming more and more popular in the modern world. This is due to the need to develop algorithmic thinking of students and the training of specialists in the technical direction. In addition, robotic kits provide a wide range for the creation of illustrative examples of the practical application of students' knowledge.

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Currently, there are 3 main types of robotics:

- sports;
- creative;
- educational.

Sports robotics is currently one of the most popular. The popularity of this type is due to competitive orientation. This area of robotics includes various types of competitions (slalom on the line, kegelring, mini-sumo, etc.). Participation in competitions of this type implies a certain knowledge base, necessary for creating robots and their programming. Sports robotics, designed to demonstrate their skills and abilities to the students who are already interested in robotics. Creative robotics serves to demonstrate the creative abilities of students. This type of robotics is characterized by the desire to create new robots that can find practical application in our life. Creative robotics is a qualitatively new level of human activity, implying the availability of basic and advanced knowledge in this area, which are necessary for the development of man-made society [Pel18, Wun16, Mur17]. Educational robotics is designed to form basic knowledge and skills in the design and programming of robots. Educational robotics is a relevant solution for student learning. Despite the fact, that educational robotics is a relatively new direction, it is developing rapidly. Dozens of companies are engaged in the development of robotic platforms for education [Kut16, Zim16]. All manufacturers of educational robotics work closely with the best specialists in the field of education from around the world to identify the main problems of the educational process. The main task of all educational robotics platforms is to increase students' motivation to learn, to improve the quality of educational programs for the preparation of competent specialists who are able to solve complex engineering problems. Different platforms solve this problem in different ways. Table 1 provides a list of the main robotic construction sets used in the educational process.

Table 1: Main educational robotics platforms

Name	Country	Manufacturer
Mindstorms Education	Denmark	Lego
TRIK	Russia	TRIK
ROBOKIT	Korea	RoboRobo
VEX	USA	VEXRobotics
FischerTechnik	Germany	FischerTechnik
Huna	South Korea	MRT International Limited
ScratchDuino	Russia	Tyrnet

The result of comparison of the technical characteristics of robotic designers is presented in Table 2.

Table 2: Comparative characteristics of robotic construction sets

	Mindstorms Education	TRIK	ROBOKIT	VEX	FISCHER TECHNIK	HUNA	Scratch Duino
Microcontroller characteristics							
CPU architecture	ARM 9	ARM9 + DSP	PIC16F887	TIVA ARM Cortex M4	ARM 9	AVR	AVR
CPU frequency, MHz	300	375	20	80	200	16	16
Wireless support							
Bluetooth	Yes	-	-	-	Yes	-	Yes
Infrared data transmission	Yes	-	-	-	-	Yes	-
Wi-Fi	Yes	Yes	-	-	-	-	-
Wireless connectivity with PC	Yes	Yes	-	-	-	-	Yes
USB interface	Yes	Yes	-	Yes	Yes	Yes	Yes

	Mindstorms Education	TRIK	ROBOKIT	VEX	FISCHER TECHNIK	HUNA	Scratch Duino
Type of connector for wired communication with a PC	Mini USB	-	USB	Micro USB	Mini USB	USB	USB B
Number of output ports	4	4	8	12	8	8	8
Number of input ports	4	-	7	12	8	6	5
System memory							
RAM	64	256	32	32	8	16	2
Persistent user memory	16	16	32	256	2	32	32
Power supply							
Battery powered	Yes	Yes	-	Yes	Yes	-	-
Battery Type	Li-On	Li Po	-		Ni Mh	-	-
Capacity mA / h	2200	2200-4200		2000	1500		
Input Voltage Characteristics	-10 V, 700 mA	11,1 V	-	9,6 V	8,4 V, 700 mA	-	-
Output Voltage Characteristics	-7,4 V	11,1 V	-	7,2 V	8,4	-	-
Charging indication	Yes	Yes	-	Yes	Yes	-	-
Software							
Supported Software	LEGO MINDSTORMS Education EV3 Software	TRIK Studio	-	Mod Kit	C-Compiler	AVR	AVR
Operating system support	Windows, MacOS, iOS, Android	Windows, Linux, Android	-	Windows	Windows	Windows	Windows, Android, iOS
Price							
Standard set, $	324,56	463,65	231,82	463,65	231,82	231,82	154,55

On the basis of the data presented in Table 2, it can be concluded that the existing proposals make it possible to effectively study robotics and programming, however, the cost of these constructs is not always affordable. One of the areas of educational robotics is modular robotics. Modular robots are one of the most difficult areas of robotics in general. Each newly added element changes the shape and capabilities of the end device, for example, adds functionality or allows the robot to move in new planes [Yim07]. To date, most of these devices remain in research laboratories. Modular construction is found in the designs of FestoMolecubes [Zyk08], CellRobotKEYiTECH [Key01] in devices created in the MIT laboratory [Rom15], and various snake robots [Lil13]. Table 3 presents an overview of existing solutions for the study of modular and group robotics.

Table 3: Comparative characteristics of robotic systems

Robot	Sensor/ Module	Motion/ Max. Speed	Size	Autonomy Time	University/ Institute	Description
CellRobot	Camera, distance, bluetooth, gyro, accelerometer	wheel, 12.5 cm/s	25.4 cm	1-3 h	KEYi TECH	The head module supports up to 20 modules to create the desired configuration. There is a possibility to program and debug control algorithms.
Cellulo	structured dense pattern sensing camera, capacitive touch	Omnidirectional ball wheel, 20 cm/s	7.5 cm	1-2 h	École Polytechnique Fédérale de Lausanne (EPFL), Switzerland	Cellulo [Özg17, Özg18] is one of the world's first tangible swarm robot platforms, combining autonomous swarms with haptic-enabled multi-user tangible interaction. Initially invented as an educational platform, research is now being conducted on rehabilitation, gaming and human-computer interaction with Cellulo in addition to education.
Colias-III	Camera, distance, light, bump, range	wheel, 35 cm/s	4 cm	1-3 h	CIL at University ofLincoln, UK	Colias-III [Hu16] is an extended version of the Colias micro-robot. It was mainly developed for implementation of bio-inspired vision systems.
Droplets	Light	vibration	4.4 cm	24h+	Correll Lab at the University of Colorado	Droplets are an open hard- and software experimental platform for large-scale swarming research [Cor15]. The team raised funds via crowdfunding to build 1000 of these 'Droplets' [Emm12]. Infinite experiments due to a powered floor that doubles as global communication medium for swarm programming.
Kilobot	distance, light	vibration, 1 cm/s	3.3 cm	3 - 24 h	Harvard University, USA	Kilobot [Rub14] is a relatively recent swarm robotic platform with novel functions such as group charging and group programming. Due to its simplicity and low power consumption, it has a long autonomy time of up to 24 h. Robots are charged manually in groups in a special charging station.
Mona	distance, bump, range, RF	wheel, 5 cm/s	6.5 cm	Perpetual	The University of Manchester, UK	Mona [Arv18] is an open-source robot mainly designed to test the proposed Perpetual Robotic Swarm [Arv17]. It has been designed as a modular platform allowing deployment of additional modules that are attached on top of the platform, such as wireless communication or a vision board. Latest version of the robot was developed as a robotic platform for education and research purposes.
SuperBot	Distance, bluetooth, IR, gyro, accelerometer	vibration	13x 6.5x 6.5 m	-	University of Southern California, USA	Reconfigurable modular robot [Shen06] with decentralized control system. The robot performs the following functions: arbitrary combination of blocks, their interchangeability, the formation of a common electrical and information network, receiving and transmitting data.

The development presented in this article is a description of the creation of a modular robo-constructor sets that will help in mastering robotics and programming.

2 Task

Thus, the purpose of this work is to improve the quality of education in robotics and programming by developing the concept of an affordable multifunctional modular robot based on small spherical robots. The concept proposed in this article is aimed at solving the following tasks:

- consideration of the basic concepts in the field of robotics and design, acquaintance of students with the current state of robotics and educational robotics;
- training students in the design and programming of robots;
- development of students' logical and creative thinking;
- development of skills to create and present projects in the field of technical creativity.

3 Development Of Methodology

Reconfigurable mechatronic-modular robots are currently robotic systems consisting of many different modules that interact with each other and exchange information to perform the objective function. The modular robot consists of separate modules that have the ability to move relative to each other, creating different configurations. Multiple construction is the principal feature that allows to talk about ensuring reliability, high adaptability of the structure, reconfigurability, its scalability, ability to self-repair, etc. in accordance with the specifics of the tasks to be solved in the conditions of uncertainty of the environment, external disturbances and the state of its own subsystems. The development of modular robots is based on the following principles:

- universality - modular robots are used to perform a wide range of tasks;
- reliability - in the event of a malfunction, the corresponding robot module can be replaced without interrupting the performance of the required task;
- availability - the total cost of robots with a modular structure is much lower than analogues due to the mass production of identical modules.

Based on the principles presented, the concept of developing a modular robot consists of two parts: hardware and software components.

3.1 The Design Of The Proposed Robot

The proposed concept involves the development of a modular robot based on small spherical electromagnetic robots and a robot control system. The small-sized spherical robot, 7 cm in diameter, is an autonomous robot module and contains a set of standard components: a controller, a control board, two motors, a communication module, a battery, two electromagnets and two servo-drivers for controlling the position of electromagnets. The pairing of two such modules is carried out by programmatically switching on electromagnets in the formation of a particular topology of the robot. The spherical shape of the robot and the servos controlling of the position of the electromagnet allow changing the orientation of the modules relative to each other both when moving in a given topology and when reconfiguring the structure of the robot. The basic functional diagram of the module is shown in Figure 1.

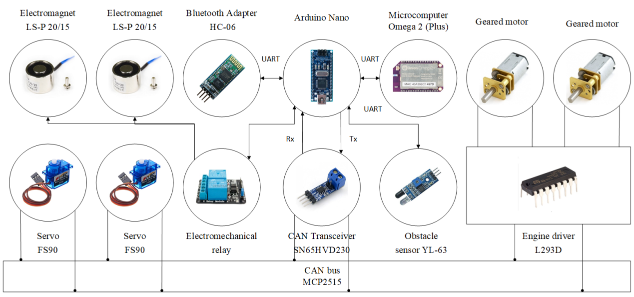

Figure 1: Basic functional block diagram

According to this concept, the spherical module of the robot should be implemented as a mobile robot with a differential drive placed in a spherical case. The kinematic diagram of the module is presented in Figure 2. In Figure 2, x and y denote the geometric position of the module center in the global coordinate system, ϕ denotes the direction of movement of the mobile robot relative to the x axis in the global coordinate system. The variable r is the radius of the wheels of the robot, and S is the distance between the wheels. Finally, ν and ω are the linear and angular velocity, respectively, and ω_L and ω_R are the rotational speeds of the left and right wheels, respectively.

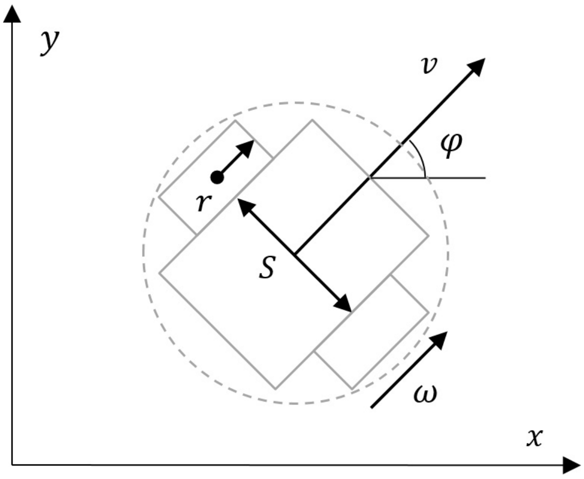

Figure 2: Kinematic diagram of the robot module

This model is one of the most simple and minimalistic representations of a two-wheeled mobile robot. In this model, the robot is represented by three degrees of freedom.

3.2 A Comparative Assessment Of The CTS According To The Functional Completeness

To implement the functionality of the robot, it is necessary to develop a software management system that includes algorithms for communication, motion control, navigation, interface modules. The block diagram of the control system is presented in Figure 3.

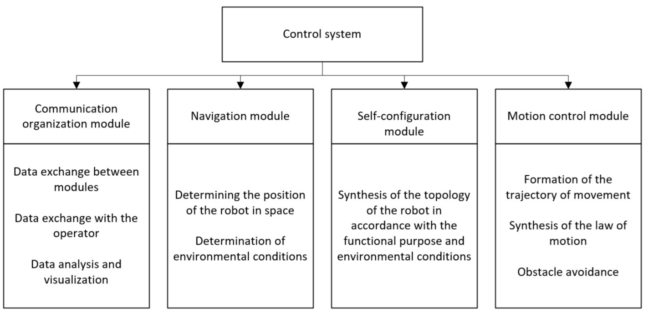

Figure 3: Control system block diagram

The following stages of the software development process of the robot control system should be highlighted:

1. Formation of requirements for the development of the robot.
2. Development of algorithms for the interaction of module components.
3. Software implementation of the module component interaction algorithms.
4. Development of robot control system algorithms.
5. Software implementation of robot control system algorithms.
6. Testing and approbation of the product performance.
7. Operation and maintenance of the robot.

The output functionality of the proposed modular robot control system is a generated set of control actions for performing operations such as:

1. Movement along a predetermined trajectory of both the entire robot and individual modules.
2. Formation of a given kinematic structure of the robot.
3. Adaptive reconfiguration of the modular kinematic structure in accordance with the environmental conditions or the required task.

3.3 Analysis Of The Cost Characteristics Of The Proposed Solution

The calculation of the cost of the components of the module developed by the robot is presented in Table 4.

Table 4: Calculating the cost of module components

Component	Quantity	Price, $	Amount, $
Microcomputer Omega 2 (Plus)	1	18,24	18,24
Arduino Nano	1	6,80	6,80
Electromagnet LS-P 20/15	2	2,55	5,10
Servo FS90	2	2,63	5,25
Bluetooth adapter HC-06	1	2,01	2,01
Obstacle sensor YL-63	1	1,39	1,39
Engine driver L293D	1	1,08	1,08
Geared motor	2	2,47	4,95
CAN Transceiver SN65HVD230	1	2,47	2,47
CAN bus MCP2515	1	1,39	1,39
Electromechanical relay	1	1,08	1,08
Battery (150 m/h, 5 V)	1	2,78	2,78
Total			54,09

Thus, the affordable cost of components leads to the low cost of manufacturing the robot, as well as further refinement and modernization, which makes it attractive to use the proposed solution in educational institutions.

4 Results

For visualization of the proposed solution, a simulation model developed in the C# programming language is presented. The result of the formation of various variants of the kinematic structure of the robot is presented in Figure 4.

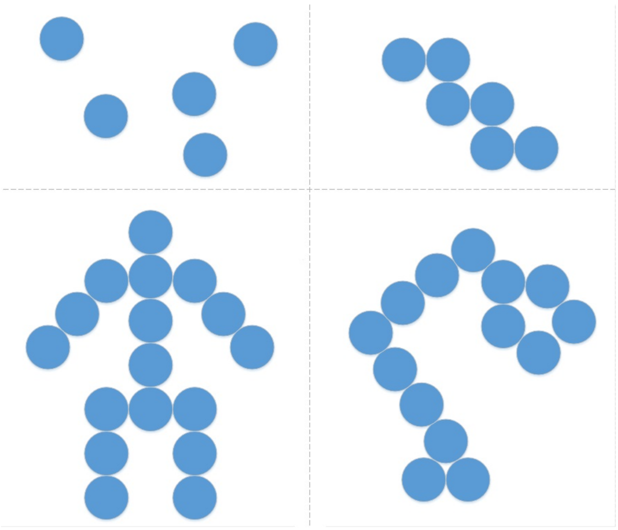

Figure 4: Simulation model of the proposed robot

Based on the given examples, it can be concluded that the number of possible configurations is limited only by the number of modules that can be used to form and change the kinematic structure of the robot, as well as their relative positions. Thus, the proposed solution will lead to an increase in the quality of education in robotics and programming by shaping the following competencies in students:

- ability to program applications and create software prototypes for solving applied tasks;
- understanding of the principles of software development in one of the high-level programming languages;
- knowledge of the design and electronic parts of robotic designers;
- knowledge of the features of typical models of robots;

- knowledge of the main types of tasks performed by programmable robots;
- ability to design and implement algorithms in programming languages;
- ability to use software development tools;
- programming skills of robot movements;
- skills of connecting and programming the robot feedback in accordance with the data collected using various sensors.

5 Discussion

This article presents the main ideas for implementing the proposed concept. Further research should be focused on the development of design solutions and the physical implementation of the robot, as well as on the analysis of the effectiveness of improving the quality of education in robotics and programming. The clear advantage of the proposed solution is the high reliability of the robot due to the use of a modular design, as well as affordable cost, due to the low price of components and ease of manufacture. In addition, the scope of the robot is not limited to the use of organizations and institutions engaged in educational activities and conducting research and development work. The proposed robot can be applied in the following areas:

- search and rescue services;
- industrial enterprises of various industries;
- private security companies.

This fact determines the possibility of applying the knowledge and skills obtained using the proposed solution for training in various fields of science and technology in the future. The development of projects, the development and modernization of the robot, the conduct of scientific and research experiments, the implementation of joint or group assignments will allow students to learn how to work in a team, set tasks, monitor their decisions, keep statistics and reports, design works and presentations, speak to an audience, and emotional control in competitions. In the process of work, students will be able to show initiative, leadership and creative abilities.

6 Conclusion

Thus, this article proposed the concept of an affordable multifunctional modular robot based on small spherical robots to improve the quality of education in robotics and programming. The ideas of both design solutions and the software component of the robot control system are proposed. The analysis of the cost of components required for the implementation of the prototype. The advantages, disadvantages and limitations of the proposed solution are analyzed, and the potential applications of the modular robot are investigated. The expected results of the implementation of the proposed solution in the educational process are presented.

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