LEGO robotics at service of education

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***Abstract*— Learning by doing seems to be the best method in education as students interact with their environment by forming it and by adapting knowledge. Interactive LEGO sets can play a great role in engineering and informatics' education from the beginning of the primary school up to the university level. This paper introduces the LEGO sets and their possible role in education, the levels, methods and tasks applied in teaching and the steps taken toward programming. The programming solutions are shown in LEGO's native programming environment and in Matlab and Simulink environment, too.**

Keywords—LEGO Mindstorms EV3, robotics, education

I. THE INTERACTIVE LEGO SETS

For nearly twenty years, LEGO has been producing building sets that include not only hardware but also software, in which the built model can be programmed and controlled. The first such set appeared in the late nineties and was called LEGO Mindstorms RCX (Robotic Command eXplorers). The brain of the set was the brick, which connected to the computers via an IR port. The brick contained 3 output and 3 input ports to which sensors and motors were connected.

The next generation of LEGO Mindstorms has been available since 2006 as Mindstorms NXT. Two years later, the NXT 2.0 version was released. In the original 1.0 kit, 3 motors and 4 sensors were available (ultrasound, sound, touch and light sensors), the 2.0 version already contained more parts, and a new sensor was added to the system, a color sensor. A USB interface was added to the brick and the program included the construction of 4 robots. The brick contained 3 output and 4 input ports to which the sensors and motors were connected. A special version of Mindstorms NXT was also released, the 'Educational version', which was primarily intended for educational purposes.

Fig. 1. LEGO Mindstorms EV3 [1]

In 2013, Mindstorms EV3 was released, which has changed significantly compared to its predecessors. 4 motors can already be connected to the brick, the robot is available via WIFI and Bluetooth, the gyro sensor is included in the kit and a new type of motor is also available. This motor is special because its axis is parallel to the longitudinal axis of the motor. The robot can also be controlled with an infrared remote control. There are descriptions of 17 robots in the set. [1]

II. THE PROGRAMMING ENVIRONMENT

Mindstorms EV3 can be programmed with its own free software, the modules required for the sensors can also be downloaded from the LEGO website. The application is available for tablets/smartphones (https://www.lego.com/hu-hu/mindstorms/apps/ev3-programmer-app), and the software for computers (https://www.lego.com/hu-hu /mindstorms/downloads/download-software). Programming is icon-based and does not require any prior training. The icons must be aligned one after the other in the correct order, and then the operating parameters must be entered within each icon. The program is built by connecting the icons. In the EV3 help menu, there is a detailed description of setting the icon parameters. You can open a new project or access previous projects on the opening screen of the software. The usual elements are also available here, as well as five 'factory' projects, complete with description, construction guide, programming aid and demonstration.

When programming Mindstorms EV3, you can place the desired instructions by placing icons one after the other. The instructions will be executed from left to right in the order of location. In all cases, the start icon must be placed from the process blocks as a starting point, and the program is closed with the stop program icon from the special blocks. By clicking on the connection point between the icons, the connection between the icons will be visible and each icon can be placed anywhere in the project. The order of execution does not change because of this, it is determined by the connections. The program can be single or multi-threaded. Most of the icons have a parameter list, which can be used to set the command mode associated with the icon. For example, the angle, time, number of revolutions, speed and power of the engine, or the detection and measurement parameters of the sensors. [2]

The Matlab (matrix laboratory) software is a mathematical system developed by MathWorks, which was developed to perform numerical calculations in the 1970s in the United States. The software, which was previously developed as an educational aid and later applied to engineering tasks, is widely used in education and in support of other, not strictly speaking, engineering work (environmental sciences, solving economic and social problems). [3]

Simulink is a new generation graphical programming and development environment related to Matlab, which can be used for modeling, simulation, and implementation. It is built with graphical block diagrams and customizable block libraries, and includes development tools such as the graphical debugger, the model editor and analyzer, and the signal monitor. The created models can be broken down hierarchically, so that more complicated models are clearer and easier to edit. The different hierarchy levels can be broken down further within the models, so they can be broken down almost to the basic units and edited in parallel.

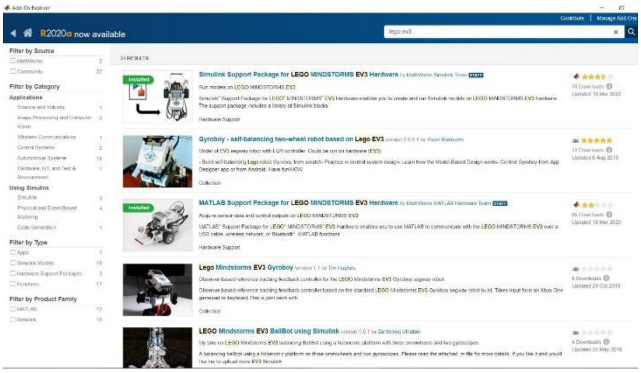


Fig. 2. LEGO Mindstorms EV3 add-ons in Matlab [3]

Hundreds of additional toolkits are available for the Matlab program system, by downloading and installing them you can solve many mathematical, engineering and other tasks. During the task solution two of these add-ons in Matlab were downloaded and installed, both from the 'official' MatWorks source. With the Matlab support package for Lego Mindstorms EV3 hardware and the Simulink support package for Lego Mindstorms EV3 hardware add-ons, Matlab can communicate with the EV3 hardware via USB, Wi-Fi and Bluetooth connections and Simulink models can be created and run with it. By installing the Simulink Support Package for LEGO MINDSTORMS EV3 Hardware additional package, the same sensors and actuators that can be found in the LEGO software become available in Matlab.

A LEGO Mindstorms EV3 (31313) programmable robotics kit was available to perform the tasks. The purpose of the construction was to build a stable, simple basic robot that can be easily assembled at any time during education, even with minimal 'Lego' practice. Among the construction instructions on the official LEGO website, the basic structure of the TRACK3R robot seemed to be the right choice for this, since the massive basic frame can be built in 10 steps, by placing the bricks on it and only minimal additions are needed to ensure mobility.

Through the Simulink interface, the computer can control the EV3 robot and instruct it to perform movements. Once we have connected our computer to the network and the Mindstorms EV3 robot is also connected to the same network, communication can be established between them. We only use the bricks and the two large engines from the LEGO Mindstorms EV3 set. The presented simple model helps to understand the potential of Matlab and Simulink in robot control during education. [4]

First, a Simulink model of the computer was created, the buttons and switches necessary to create the model from the Simulink Library browser were chosen, and then the Mindstorms EV3 control panel for modeling was created.

III. LEGO MINDSTORMS EV3 IN EDUCATION

The LEGO Mindstorms EV3 mobile robot set contains all the elements that can be used to demonstrate the structure, main parts and programming possibilities of robots at all levels of education. When compiling the material, we progress from simple tasks ('move the robot') to more complex tasks requiring sensors and even multiple motors. The tasks on the own graphical programming interface of the LEGO Mindstorms EV3 robot set and on the Matlab/Simulink interface are both presented. Experience shows that early technical and science education can result in greater engagement among students in the long term. [5] [6]

The first task for those new to the LEGO Mindstorms EV3 robot is to move the robot. First the robot was connected to the computer via a Bluetooth connection and the linkage can be seen in the lower right corner of the graphical programming interface. The status of the motors and sensors can also be seen here (port view) and the program can also be started from here. The port view shows that in this case three sensors are connected to the Mindstorms EV3 brick, infrared sensor for port one, color and light sensor for port two, and gyro sensor for port four.

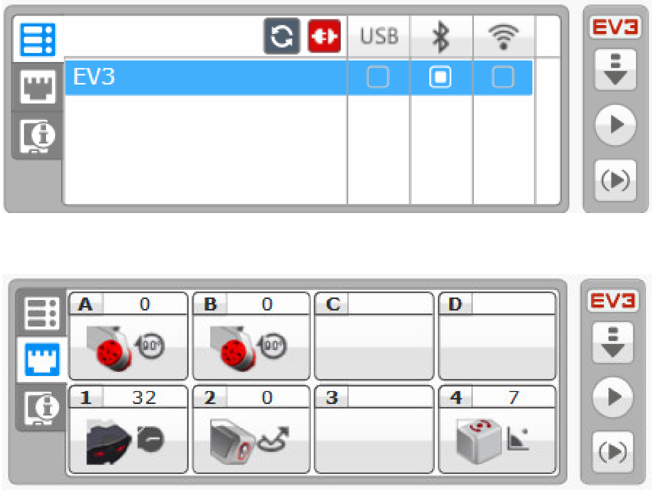


Fig. 3. Connection and port view of the EV3 set

The second task is based on what was learned during the first task and a sensor, the infrared sensor, will be used. The infrared sensor can be used to determine the distance of objects in the environment. There are two ways to use the sensor, in one the approach or distance is compared with a predetermined value, while in the other case a given distance is measured. The infrared sensor can also be used as the receiver part of the infrared transmitter (remote control) included in the kit, in which case the robot receives instructions or searches for the source of the infrared signal (beacon mode) and the degree of angular deviation from the signal source can also be set. The latter can be useful when performing more complex tasks, when, for example, the infrared remote control is part of a pallet and the forklift uses the infrared sensor to locate the pallet and turn completely in front of it to lift it.

When avoiding obstacles, the infrared sensor placed at the front of the robot detects obstacles in its range and the actuator intervenes when the preset value is reached. There are several options for avoiding obstacles, even the joint work of several sensors can help Mindstorms EV3 progress. During programming, a switch is incorporated into the program, where the state of the infrared sensor determines the true or false branch. The sensor setting can be less than, less than or equal to, equal to, greater than or equal to and greater than. In general, we use the smaller or equal value for object avoidance, according to the movement speed of the Mindstorms EV3 robot, we specify a minimum distance of at least 20 centimeters for obstacle avoidance.

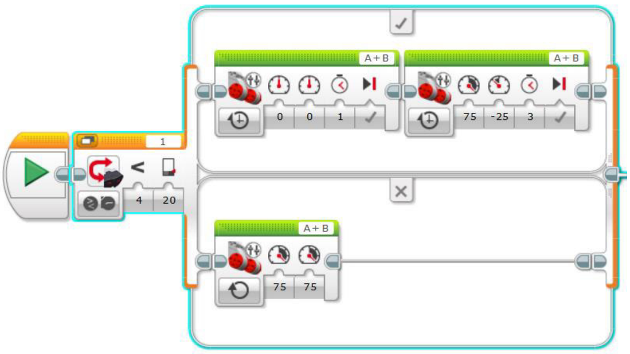


Fig. 4. Object avoidance programme

For the robot to continuously move and constantly avoid obstacles, the entire program is in a loop, so the program runs endlessly and only stops when it is switched off.

In the true and false branches, tank drive was put, in the false branch we program continuous straight forward movement, and in the true branch stop and turn movements. The time of these movements and the angle of rotation determine the dynamics of the Mindstorms EV3 robot, which can be important, for example, in the movement of the interacting robots of a swarm of humanoid mobile.

When running the program, the Mindstorms EV3 robot moves straight ahead with 75 percent engine power for both engines, and when it gets closer than 20 centimeters to an obstacle, it stops for 1 second and then turns through 3 seconds (with 75 and -25 percent engine power). This movement lasts until there is an obstacle closer than 20 centimeters in front of the robot when it continues straight, indefinitely due to the inclusion of the loop.

By completing the task, students can understand the role of the tank drive, the switch and the loop, their application possibilities, as well as the general role of sensors in switches and the application possibilities of the infrared sensor.

By building a Simulink model of the Mindstorms EV3 robot in a Simulink environment, you can program a robot that avoids objects or obstacles with the help of its infrared sensor, too. This can be achieved with several settings, in one example, the Mindstorms EV3 robot moves straight ahead, then changes direction upon detecting an obstacle within a given distance. The opposite of this can be the case when the robot is continuously moving laterally, but the direction of movement is determined by the value of the predetermined distance, above it moves to the right and below it to the left.

For the object search, constant values must be entered, based on which the constant speed of the Mindstorms EV3 robot is determined, and the distance value is set on the infrared sensor. The speed was determined as 0.25 m/s.

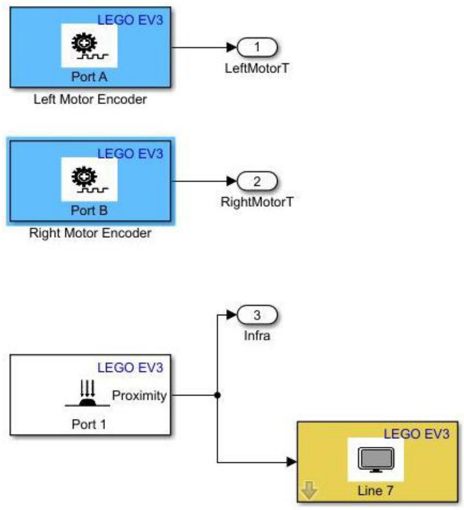


Fig. 5. Motors, sensor and display in Simulink

If the distance detected by the infrared sensor is greater than 30 centimeters, it moves to the right, otherwise to the left, so if an object gets too close, the Mindstorms EV3 robot changes direction and avoids a collision. The current distance is continuously displayed between 0 and 100 on the robot's display.

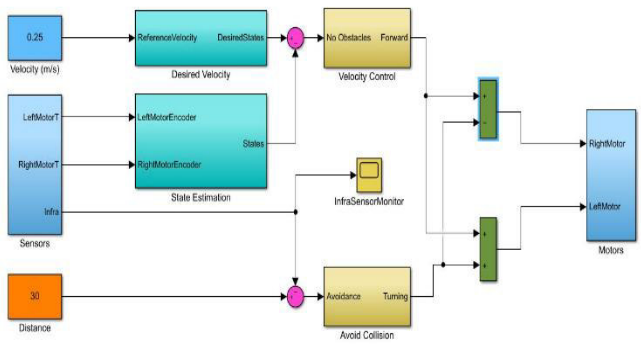


Fig. 6. Object avoidance model in Simulink

Distance measurement was also performed with the infrared sensor in a Simulink model as Mindstorms EV3 infrared sensor and its output was the result of distance measurement. During the run of the Simulink model, the robot displayed the distance in the seventh line of the brick display, and the same value appeared graphically on the scope. For the correct setting, the sampling time of the infrared sensor had to be set from the 0.1 second in the basic setting to 0.001 second, as previously the values displayed on the scope were unintelligible.

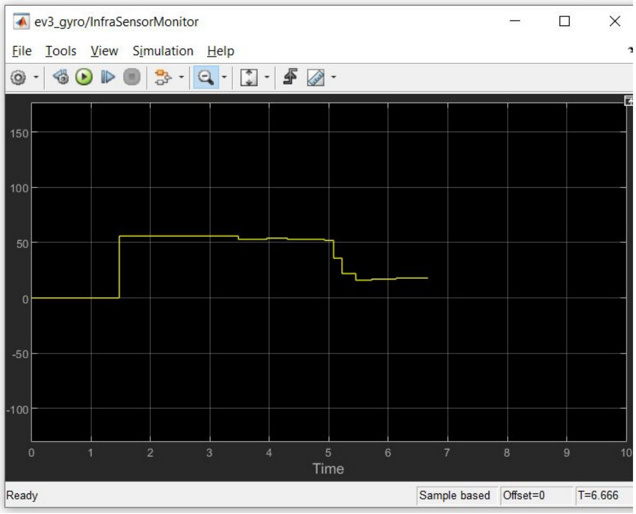


Fig. 7. Distance measurement scope

In the third task, a similar model was built to the first task, but with different sensors (color and light sensor).

Line tracking is a simple task for a human being. Looking in front of us, we follow the line with our eyes at a distance of a few meters, using our other senses as well, so we can walk along the designated path in a roughly straight line.

In comparison, the robot does not see ahead, the color and light sensor on the Mindstorms EV3 robot looks down, it only sees the one-centimeter part in front of it. It must be noted that modern robots already use other tools for spatial orientation, machine vision, cameras, distance sensors, laser scanners help with their navigation (this is called natural navigation, when the robot makes a map of the room for itself and uses this to find its way around [7].

Industrial robots can use several methods during line tracking: they follow a fixed magnetic line or travel on a line operating on the induction principle, although the cost of building them is high and they are not mobile systems, and their change is difficult and expensive.

The color and light sensor of the Mindstorms EV3 robot can choose between eight different colors and can distinguish between dark and light. By modeling its industrial environment, Mindstorms EV3 color and light sensors enable accurate color-based object sorting.

In practice a black line is used (a path made of insulating tape, as its flexibility and width are suitable for the task) as a line (path), and line tracking can be done in two ways: the robot's program based on the shade difference between the dark and light parts, or black colored parts differ other surfaces. Generally, the latter method is more reliable.

At the start, the robot is started from the black line, the Mindstorms EV3 robot 'scans' the path forward and if the detected area below is black it moves to the right, as soon as it leaves the black area and detects a light part of the space it turns back to the left. An important aspect for accurate line tracking is the optimal choice of travel speed because if the robot turns too quickly it will permanently leave its path and will not find its way back. Due to the method described above, the robot moves forward by 'jerking' left and right.

For programming, the switch and loop used in the second task are used again, the switch is set here by the color and light sensor. If the condition is true, the robot moves to the right, and if it is false, the robot moves to the left, the set speed is 50 percent for both motors: movement to the right is 50 and 50, while movement to the left occurs at 50 and -50 percent motor power in the steered drive setting.

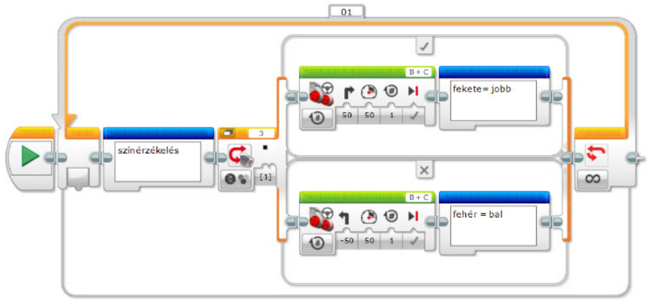
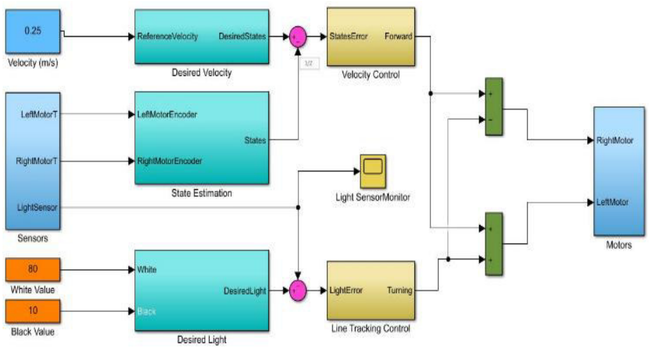


Fig. 8. Object avoidance model in Simulink

The same task is solved in the Matlab/Simulink environment as follows. The path tracking is carried out in the same environment as when using the 'own' software, so black insulating tape on a white/light basis represents the route to be followed, but in the Simulink model the dark and light parts get their own value and the program compares this during its progress. By the way, this solution would also be available on the 'own' graphical programming interface, there I chose the other method for the sake of simplicity and the presentation of the two options. For line tracking, constant speed and color values must be entered. The value of the speed was determined at 0.25 m/s, this value is still adequate for the correction in case of leaving the track.

If, based on the intensity of the reflected light, the sensor moves on the black color, the robot continues its path straight, and if the light moves more towards the light color (white color), it corrects its path by changing the two motors travel speed and the direction of rotation of the right big motor, while the direction of rotation of the left big motor does not change. The word 'Lite' appears in the fifth line of the Mindstorms EV3 robot display and continuously shows the light intensity value during the program's run (typically between 0 = black and 75-80 = white). The Mindstorms EV3 robot does not 'jerk' with this control mode, its progress feels much more continuous than with trajectory tracking based on 'black or white' perception.



With the color and light sensor, a light intensity measurement (reflected light intensity) was also performed in a Simulink model environment. In the simple model the Mindstorms EV3 color and light sensor was included, and its output was the result of the intensity value of the reflected light. During the run of the Simulink model, the robot displayed the light intensity in the seventh line of the brick display, and the same value appeared graphically on the scope.

Both methods are suitable for track tracking, in the case of one the progress on the line is more 'sophisticated', but the appropriately chosen speed is perhaps the most important factor in both cases. If the robot moves too fast, there is a greater chance that the Mindstorms EV3 robot will leave its track and not find its way back to the designated black line.

IV. SUMMARY

LEGO Mindstorms EV3 sets are available for schools and for universities for educational purposes. From the primary school level up to the higher educational level these sets seems to be a good tool for programming education. In this paper different programming tasks were introduced, and different tools were shown. Matlab and Simulink programming environment could be a good solution beside the LEGO's 'native' programming environment.

At the Óbuda University Alba Regia Technical Faculty these versatile LEGO sets are used at different educational levels. LEGO sets are in education in Bejczy Antal junior programming competition for the primary school students, Bejczy Antal LEGO programming contest for the secondary schools and Multiagent robotic systems on university level.

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