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Meelis Nopri

LEGO MINDSTORMS NXT: Firgelli L12-NXT Actuator

Bakalaureusetöö (6 EAP)

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LEGO MINDSTORMS NXT: Actuators

Introduction

In the modern world, technology plays a big part of our lives. Since the microprocessor was invented, devices which use them have become cheaper, accessible and incredibly complex. From personal computer to a microwave, everything has a small processor to run things. For most of the people, these things come naturally and no one gives much thought to what makes them tick. In this world, people who know how to make and program complex machines and gadgets are of very high value. Therefore the education system must accommodate that need for specialists.

Children develop interests from very young age and so it is important to give them opportunities to try different things early on. If something piques their interest it is essential to feed that. Schools must provide means for this. One way to ease children into more technical sciences is LEGO MINDSTORMS NXT.

The LEGO MINDSTORMS NXT is an entry level robotics kit. It consists of a control block, lego blocks and several sensors and engines. It is meant for ages 8+ but it does not mean it is not suitable for older people too. It is a perfect learning tool for people who would like to learn more about programming devices that surround us all the time. What makes it good is that it is also fun, not just educational. This means that children will not get bored of it as it very much resembles a game.

The LEGO MINDSTORMS NXT kit comes equipped with several sensors but its options are still limited. That is why there are several companies like Firgelli and Vernier, who make extra sensors compatible with LEGO.

The programming itself is done in a graphical environment. It doesn't involve any codewriting, as programs are written by putting blocks on a canvas and changing their attributes to change, what they do.

This paper is written to introduce an extra device for LEGO MINDSTORMS NXT. The device is called an actuator and it is made by Firgelli. The paper consists of three chapters and is structured as follows:

1. Introduction to actuators. Provides answers to questions like "What is an actuator?" and "Where are actuators used?".
2. The Firgelli L12-NXT actuator specifications and how-to guide. Here the reader learns how to attach the actuator to the robot and how to start programming it.
3. Exercises. To better understand what the actuator is capable of, several problems are presented for solving. The reader will learn different aspects of the programming environment as well.

The appendix contains a CD with solution files. These provide one possible solution to each of the problems.

1 Introduction to Actuators

This chapter provides basic introduction to what are actuators, what makes them tick, where to use them and a short overview of types used to accomplish different tasks.

1.1 Benefits of actuators

Men have been making tools for a long time. Each tool has a purpose. Having realised that some problems are easier to confront with proper techniques and utilities, man has created many helpful constructs. One basic need was making moving heavy objects easier. For this purpose the first men set round logs on the ground and by placing the heavy object on a rolling surface were able to move much bigger things. Thus, a rudimentary wheel was born. The point is that for most tasks there is a tool, that makes it easier to perform. And if the tool doesn’t exist yet, it doesn’t mean it cannot be invented. It’s essential to have proper means to accomplish a job and men thrive to find better all the time.

Often, the environment in which we work in sets certain constrictions to which tools we can use. Sometimes there’s not enough space to use large machinery or sometimes the surface is too soft to use heavy machinery. Or you need really precise motion. For example you can’t use a lever to move a big rock, if you don’t have the space to move the lever. One of the solutions to make more compact, yet very powerful and precise tools, is to make a mechanism that is able to take one sort of energy and convert it to other.

Actuators are mechanisms that take one sort of energy and converts it into controlled motion. Today, there are many fields in which actuators are used. Perhaps one of the most basic tasks that actuators accomplishes is making fixing a broken tire a lot easier. A carjack is placed under the car, you rotate a lever or a screw and the car is lifted up. In this case circular motion is used to create linear motion. Another common machine is a forklift. There, usually pneumatic or hydraulic cylinders are used to move the fork up/down. Here, the potential energy of fluids or gases is used to create a simple linear movement enabling the forklift to haul heavy loads.

There are many different types of actuators which will be discussed in the following paragraphs.

1.2 Physics behind actuators

So what does the word actuator mean? If we look from the dictionary, we find:

actuate – 1. To put into motion or activate; activate [7]

Actuators are devices to move things. When moving things one needs to apply force. Actuators take one form of energy or motion and convert it to another. In a perfect world this wouldn't be a problem, but unfortunately in reality we are unable to make a 100% efficient energy conversion.

The efficiency of an actuating mechanism is expressed by the formula

$$\varepsilon = \frac{\text{useful work}}{\text{spent energy}} = \frac{\text{output energy}}{\text{input energy}}$$

The result of this formula is usually lower than 1 and expresses the energy conversion factor. It shows how much energy is thermally dissipated via reasons like friction, magnetic losses, eddy currents etc. [1] Actuators are usually quite efficient. Some ball screw actuators can have efficiencies up to 0,9 as typical lead screw actuators have efficiencies around 0,5 [3]. The factors which have and effect on the efficiency are many in number and depend on factors like the state of the machine (how well is the actuator maintained), the technology used etc.

Actuators employ several physical phenomenons. Most basic type is mechanical actuators. These convert one type of motion into another. The motion may be introduced by manual labor or electric motors. More common types are leadscrews and ballscrews. The other widely used energy source is the potential power of pressurised gases or fluids. These are pneumatic and hydraulic actuators respectively. Some materials have the capability to expand when voltage applied. Devices using that interesting quality are called piezoelectric actuators [9]. A similar type of actuator is the wax actuator, where heat is used to expand the material, not voltage.

In the next chapter different actuators and how they work will be explained in further detail.

1.3 Types of actuators

Depending on design actuators can move very big loads precisely. They are used for precision as well as power. However, they are not limited to only big and powerful. Microactuators can be used as very specialised tools in various electrical systems as some piezoelectric actuators can have accuracies better than 1 micrometer [9]. Therefore actuators have a very wide useful range. For different purposes one needs a specialised machine though. Next there’s a list of the most common technologies used in actuating mechanisms.

Screw operated actuators:

- **Jackscrew** (Figure 1)– a device operated by turning a leadscrew. Basically the contraption consists of a straight shaft which has a helical groove. A bolt with a handle may be placed on the shaft. When twisting the bolt it is lead up or down the shaft depending on the direction of the rotation. This is a very simple contraption and is used very widely. Most common uses are carjacks and bench clamps.

Figure 1 A jackscrew [10]

- **Ball screw** (Figure 2)– this consists of a threaded shaft that is a spiral raceway for ballbearings. The advantage of this system is that it has very low internal friction.

They have very low tolerances and are therefore very precise as well as are able to withstand high thrust loads. This system is used in aircraft to move control systems and also robots and precision assembly equipment.

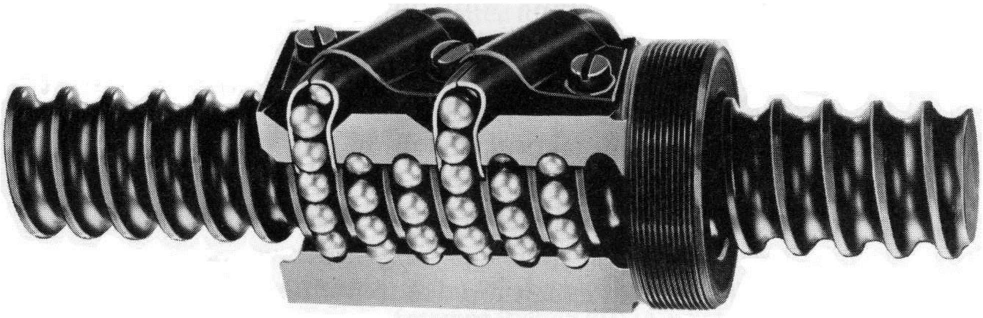

Figure 2 A ball screw [11]

- **Roller screw** (Figure 3)– it's similar to design to ball screw but uses rollers instead of balls. The advantage is that they can be smaller and with the same efficiency. They are even more precise.

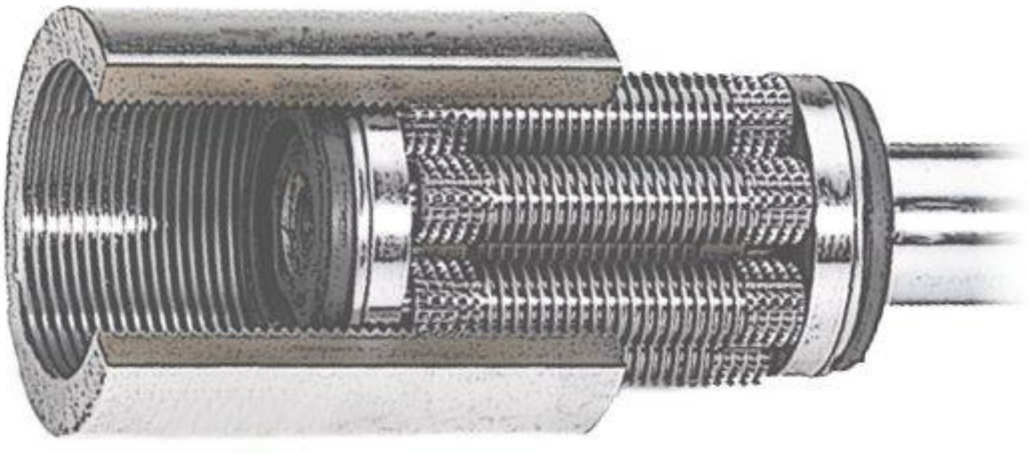

Figure 3 A roller screw[12]

Next are wheel and axle operated actuators – this is a very simple concept. By rotating the wheel connected to and axle you make a linear member of the system (chain, belt, rope etc) move. For example this is used with wells. A bucket is attached to the end of the chain and then lowered and raised by rotating the handle attached to the axle.

Cam actuator – A cam is a cylinder with an irregular shape. As it rotates it strikes one or more levers along its circular path. This provides a relatively limited travel. The most common use is in automobiles where camshafts (Figure 4) are used to operate intake and exhaust valves of the cylinders.

Figure 4 A camshaft [13]

Hydraulic fluid actuator – Typically a hydraulic actuator consists of a piston inserted into a hollow cylinder. The piston is then moved by pressurising or depressurising sides of the piston. Thus controlled linear displacement of the piston is achieved. Used widely in various heavy construction machinery like excavators (Figure 5) where the manipulator is operated by hydraulics.

Figure 5 An excavator [14]

Pneumatic actuator – Similar in concept to hydraulic actuators only instead of fluids compressed gas is used to provide necessary pressure. However, there are several differences between hydraulics and pneumatics. Hydraulics are more powerful as liquids don't absorb supplied energy. On the other hand pneumatic cylinders are easier in design and have a longer lifetime and require less maintenance. [15]

Piezoelectric actuator – Certain materials expand when introduced to voltage. This is called the piezoelectric effect. The expansions are tiny, so this method is only used where little, but very precise, movements are required. One everyday application is your earphones, where tiny piezoelectric materials vibrate very fast, creating what human ear perceives as sound.

Electro-mechanical actuator – these are very similar to mechanical actuators only the control knob is connected to an electric motor. The electrical motor provides rotary motion to be converted to linear motion.

Linear motors – this is a rotary electric motor laid down on a flat surface. This requires no lead screw since the motor already moves in a linear fashion. These have low load capacity compared to other types of linear actuators. This is used most commonly in train transport, namely monorail trains,. High acceleration versions include railguns and coilguns (Figure 6).

Figure 6 A handheld coil gun [16]

Wax motors – have three components: a block of wax, a plunger bearing on the wax, an electric heater to heat the wax. When wax is heated, it expands and drives the plunger outwards. This provides for a short range of motion. However the motion is smooth and gentle. These are sometimes used to replace magnetic solenoids (a coil in a tight helix which can expand when a current is introduced).

Telescoping linear actuator – These are used when space restrictions are tight. They have a range many times greater than the unextended length of the actuating member. This is achieved by having several concentric tubes around the same length. Used with pneumatic and hydraulic cylinders. [2]

This covers most common types of actuators and their uses. In the next chapter the Firgelli L12-NXT Actuator, which is used for this paper, is introduced in further detail.

2 Firgelli L12-NXT Actuator

The actuator used in this case is produced by Firgelli. Among other things it is compatible with NXT robots used as test subjects for writing this paper. This paragraph is the description of the L12-NXT.

2.1 Introduction to Firgelli L12-NXT

The Firgelli L12 Actuator (Figure 7) is the first member of the L series family, which is a line of micro actuators. This particular actuator is powered by an electric motor so it falls under the category of electro-mechanic actuators.

Figure 7 The Firgelli L12-NXT actuator [18]

It consists of silver rectangle which houses the shaft, a plastic cap for the small electric motor and an input jack to connect the device to the controller.

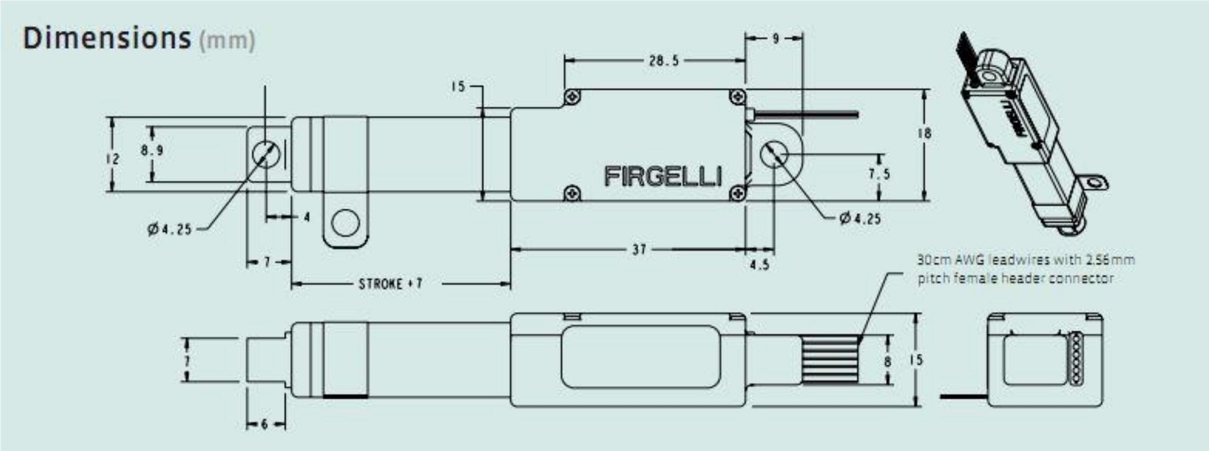

Figure 8. Dimensions of the L12-NXT [8]

The device also features several parts which are compatible with LEGO, so it can be connected to robots. This chapter was the outside of the actuator. In the next chapter the performance and capabilities of the device are discussed.

2.2 Specifications and definitions

Before we dive into the specifications (Figure 9) of the actuator we first must understand what a certain thing means. So here's a list of definitions for the parameters given in the chart below:

Peak Power Point - maximum power and the speed it can move at that force.

Peak Efficiency Point - the speed and power at which the device is the most efficient.

Backdrive Force - the maximum force the actuator is able to hold when powered off.

Mechanical Backlash - the clearance between two mating components.

Feedback Potentiometer - a potentiometer is used to determine the position of the shaft.

Duty Cycle - the period of time the motor actually runs out of the time to complete the task at hand.

Ingress Protection Rating - a rating coined by European Committee for Electro Technical Standardization to determine the protection the device has from outside factors [19].

Stall Current - the maximum amount of power the motor can draw. This is measured by powering up the motor and then manually stopping the shaft from moving [20].

L12 Specifications

Gearing Option	50	100	210
Peak Power Point [1]	12 N @ 11 mm/s	23 N @ 6 mm/s	45 N @ 2.5 mm/s
Peak Efficiency Point	6 N @ 16 mm/s	12 N @ 8 mm/s	18 N @ 4 mm/s
Max Speed (no load)	23 mm/s	12 mm/s	5 mm/s
Backdrive Force [2]	43 N	80 N	150 N

Stroke Option	10 mm	30 mm	50 mm	100 mm
Weight	28 g	34 g	40 g	56 g
Positional Accuracy	0.1 mm	0.2 mm	0.2 mm	0.3 mm
Max Side Force (fully extended)	50 N	40 N	30 N	15 N

Mechanical Backlash	0.1 mm
Feedback Potentiometer	2.75 kΩ/mm ± 30%, 1% linearity
Duty Cycle	20 %
Lifetime	1000 hours at rated duty cycle
Operating Temperature	–10°C to +50°C
Storage Temperature	–30°C to +70°C
Ingress Protection Rating	IP–54
Audible Noise	55 dB at 45 cm
Stall Current	450 mA at 5 V & 6 V, 200 mA at 12 V

[1] 1 N (Newton) = 0.225 lb, (pound-force)
[2] a powered-off actuator will statically hold a force up to the Backdrive Force

Figure 9 Firgelli L12 specifications [8]

The L12-NXT is similar to L12. The main difference is the power. L12-NXT only has a 50mm stroke and unloaded can move weights at 12 mm/s and they push 25N.

2.3 Getting the actuator ready to be programmed

Before you can start using your actuator you first need to set up the environment to start controlling it. First you need to install LEGO MINDSTORMS NXT v2.0 program. This program provides a GUI (Graphical User Interface) which enables users to graphically program robots. The user has several icons which can be configured and connected with wires creating a program flow. Then the program can be uploaded to the robot and it can be run from there. LEGO MINDSTORMS NXT v2.0 is meant for entry level users who are just starting to learn about robotics.

Next you need to import the NXT block for the actuator which can be found at the Firgelli L12-NXT page [21]. The downloaded software is in ZIP format and first needs to be unpacked. Then you need to open the import wizard (Figure 10). This can be found at “Tools” -> “Block Import and Export Wizard”. Next step is to select the folder to which you have unpacked your actuator block.

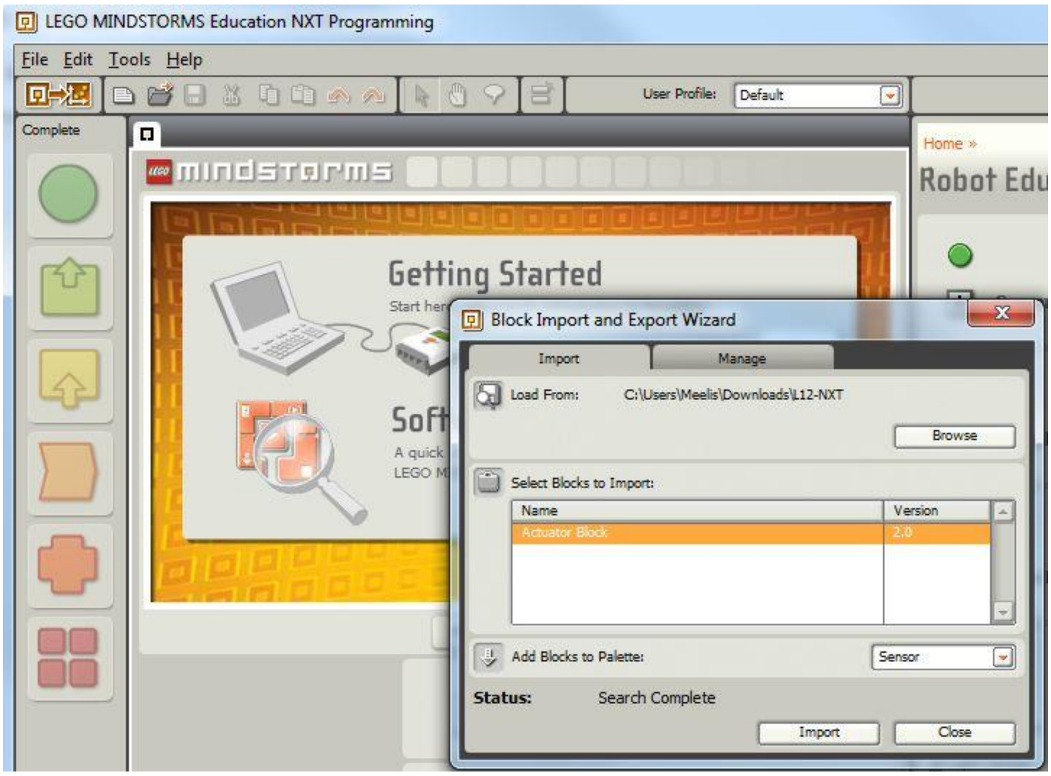

Figure 10 Importing a new block to LEGO MINDSTORMS

After you’ve selected the correct folder, you should be able to choose the block from the Import list. Also make sure to select Sensor option from the “Add Blocks to Pallette” dropdown menu. After that you can click the "Import" button and the actuator block is added to your pallette. It can be found under the Complete Pallette under Sensors (Figure 11).

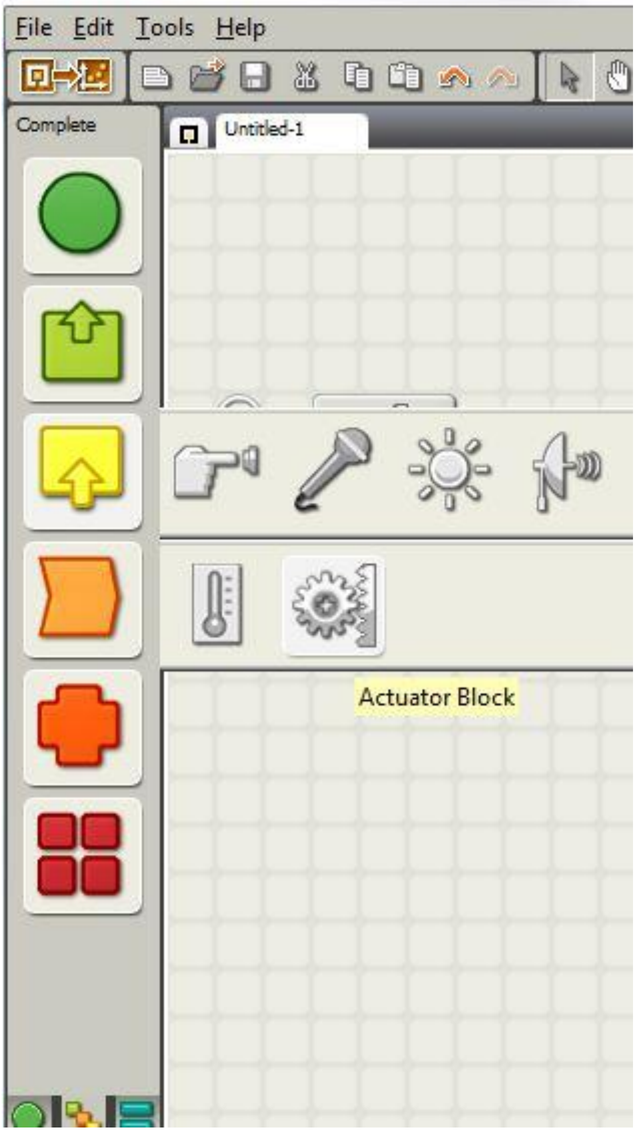

Figure 11 The actuator block in GUI

Figure 12 The actuator block options.

To start making a new program one just needs to click “File” -> “New” in the program window and you can start placing icons on the canvas. Each sensor or motor has a block which can be configured according to your needs. The actuator block (Figure 12) contains 6 options you can vary.

Port: The port to which the actuator is connected to on the robot.

Direction: Shows whether the shaft will move in or out.

Speed: Determines the speed at which the shaft moves.

Distance: Determines how long the stroke is. You can decide between mm and holes, where hole is the standard distance (8mm) between LEGO block posts.

Wait: If the checkbox is ticked then only one motor can run at the same time. This means the block will complete its action before anything else can happen.

Manual: The manual mode enables the user manipulate the shaft by pressing the Left and Right buttons on the main block.

After the program is completed it can be uploaded to the robot itself by pressing the “Download and run” button on the bottom right corner of the canvas.

Next the robot needs to be connected to the PC so it can be programmed.

2.4 Connecting the robot

The robot comes with a central control block and several sensors. The most important part is the central block which houses all the ports that the sensors and motors are connected to. The robot connects to the PC with an USB cable. Once the robot is attached, the programs written in the GUI can be downloaded to the control block and run.

The main block has 8 ports. 1 for the USB cable, then the 4 ports for sensors (labeled 1-4) and then 3 motor ports (labeled A,B,C). The actuator must be connected to one of the motor ports.

Since the actuator isn’t the only programmable part of the robot, the next part is dedicated to the sensors included with the robot kit.

2.5 Other sensors

The robot kit comes equipped with 4 extra sensors.

Light Sensor - This sensor has two modes. First it can detect the general luminosity of the room. Second, if the room has difficult lighting (too bright for example), it can also generate it’s own light. The sensor block allows to define a value for trigger point. Depending on which side of the trigger point the values fall, the sensor generates a boolean type result. This sensor can be used as a way to avoid obstacles.

Ultrasonic sensor - Similarly to the light sensor, this sensor lets you define a trigger point and returns a boolean value. The sensor puts out an ultrasonic signal to determine a distance to objects. The maximum range is 250 cm.

Sound sensor - This sensor also takes a trigger value (loudness of the sound) and returns a true/false value depending on which side of the trigger point it fell.

Touch sensor - This sensor has a button which can be pressed. It has 3 settings (pressed, released, bumped) which return a boolean value.

After all the necessary sensors and motors are connected, the robot can be programmed and programs executed. In the next chapter tasks will be required of the robot and the robot will then be programmed and built according to need.

3 Exercises

The following chapter contains exercises. Exercises are meant to show what tasks the actuator is able to perform. The first task is simple which each following exercise increasing in difficulty. This is so the solver has a learning curve and has to think more with each challenge.

Each task has a certain structure. This structure is implemented to make it easier to write and also so they could be used as learning materials later on. Each exercise is as follows:

- Level - to show the expected difficulty of the exercise.
- Goal - describes elements the solver learns during the task.
- Necessary knowledge and required equipment. Basic assumed equipment is computer with LEGO MINDSTORMS Education NXT, the actuator and the NXT control block with wheelbase (meaning it can be programmed to move). To achieve each goal, the solver must understand how the programming software works.
- The exercise itself. Requirements for the exercise to be completed successfully.
- Provides one idea how to solve the task.
- Provides one possible solution. The solutions are solved in LEGO MINDSTORMS Education NXT 2.0 environment and are included on the CD, which is in the appendix. The solution also involves a picture of the robot, if necessary, for better understanding of the task. The picture of the solution in the graphical environment is on the page after the exercise.
- Comments about the task (optional)

3.1 Exercise 1

Level: Easy

Goal: To introduce basic movement of the actuator and the robot.

Requirements: Default package

Exercise: Move the robot 5 rotations, fully extend the actuator, move the robot back to starting position, retract the actuator. The purpose of this exercise is to get an idea, what the actuator actually does and to get a feel how the programming environment works (sequencing tasks and such).

Idea: Connect the actuator to the NXT control block. None of the actions need to happen simultaneously, so just create a linear program with 4 blocks, 1 for each action (Figure 14).

Comments: If for some reason the actuator isn't working, check that the actuator is in the engine port not the sensor port.

Solution:

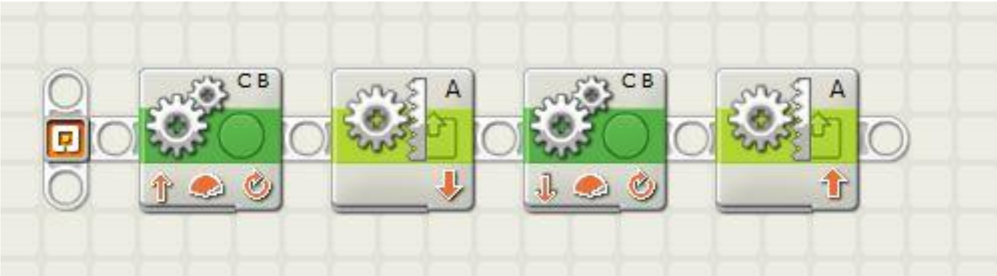

Figure 14. The solution to Exercise 1.

3.2 Exercise 2

Level: Medium

Goal: Learning to use multiple sensors together, specifically actuator and ultrasonic sensor.

Requirements: Ultrasonic sensor, three obstacles no further than 250cm.

Exercise: Using lego blocks, the actuator and the ultrasonic sensor, measure the distance of the robot from 3 random spots. Show each distance on the screen. The robot itself cannot be moved. That means you cannot use wheels to turn the robot. Afterwards retract the actuator to starting position. The idea is that the robot can be used as a sentry. Without moving, it can measure the distance to 3 different areas. With some additions, it can be programmed to do it for longer periods of time.

Idea: Build a revolving tower (Figure 13). Attach the actuator to one edge of the tower base. Moving the actuator shaft in and out will also rotate the tower. Placing the ultrasonic sensor on the top of the tower also changes the direction it faces.

Figure 14 An ultrasonic sensor on a revolving platform.

Comments: The tutorial to show distance on the display can be found in LEGO MINDSTORMS Education NXT under Ultrasonic Sensor tutorials, specifically the Display Text tutorial.

Solution:

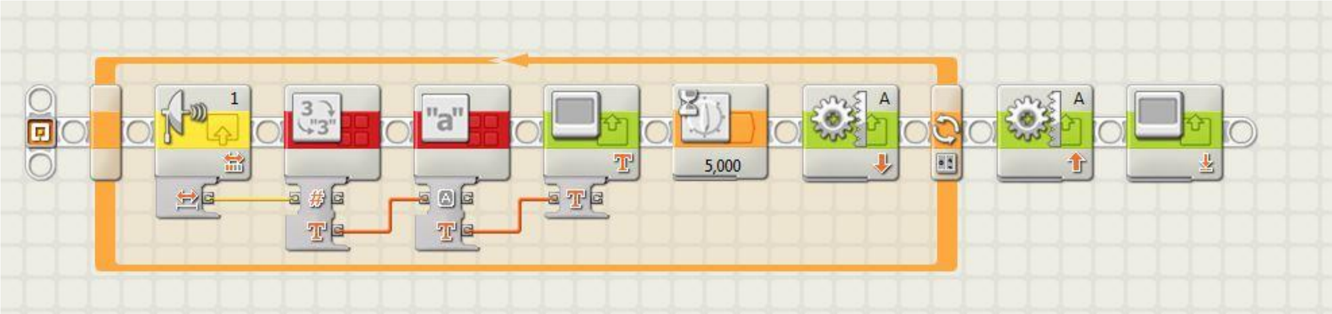

Figure 15 The solution to exercise 2.

Here the robot first measures the distance, displays it on the screen and then changes direction of the ultrasonic direction. It does that 3 times, giving a new readout every time. After the loop has finished, the actuator shaft is retracted and the display reset.

3.3 Exercise 3

Level: Hard

Goal: Making sensors trigger in a cascade through one input.

Requirements: Sound sensor, touch sensor.

Exercise: When a loud sound is heard, the actuator is triggered. On the other hand, the robot can only move, when the touch sensor is pushed down. The goal is to get the robot to move in a square for 10 seconds. The robot must be constructed in a way that the actuator activation triggers the touch sensor.

Idea: Make the actuator push the button on the touch sensor. While the button is pressed, the robot moves, when released, it stops.

Solution:

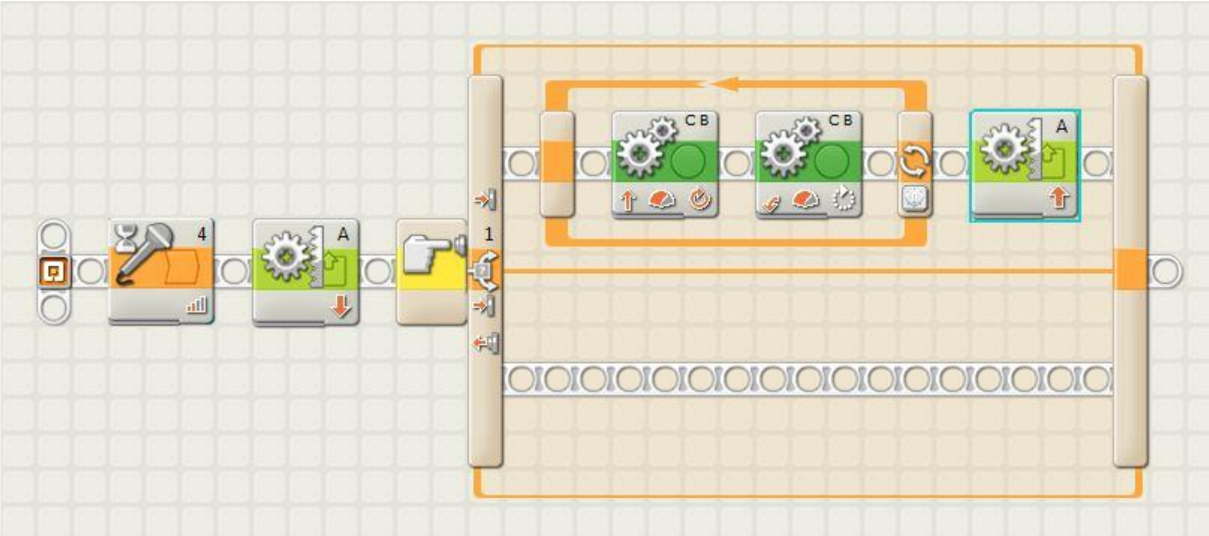

Figure 16 The solution to Exercise 3.

When constructing the robot, the actuator is connected to the touch sensor. When a loud sound is detected, the actuator moves outwards, pressing the button of the touch sensor. In the program the switch makes the robot move when the touch sensor is pressed. The loop inside the switch makes the robot move in a square for 10 seconds, after which the loop ends and the actuator retracts, ending the program.

Summary

The first part of this paper introduces actuators as a whole. At first it is explained what is an actuator. Then, most common types of actuators and their working principles are explained. Also some examples are provided so the reader knows where they are used in practice.

The second chapter is concerned with the actuator at hand, namely the Firgelli L12-NXT. It provides an overview of the actuator itself. Next instruction on how to start programming the actuator and how to connect sensors to the robot is explained.

The third and final chapter has 3 problems with increasing difficulty for the learner to solve. Each problem comes with a solution, idea on how to solve it and necessary comments. The CD with possible solutions is provided in the appendix.

Altogether this paper serves as a studying material for someone who hasn't had any contact with robotics and/or actuators before. When the reader has read the materials and completed the exercises he/she should be able to have basic concept of robotics and how many real time systems work. Teachers who have knowledge of English, can use this paper as material to teach using the actuator with LEGO MINDSTORMS NXT robotics kit.

LEGO MINDSTORMS NXT: Firgelli L12-NXT aktuaator

Kokkuvõte

Meelis Nopri

Bakalaureusetöö

Bakalaureusetöö esimene osa kirjeldab aktuaatoreid tervikuna. Kõigepealt selgitatakse, mis on aktuaator. Seejärel kirjeldatakse põhilisi aktuaatoritüüpe ning nende tööpõhimõtteid. Lisaks on ka näiteid reaalsetest kasutusaladest, et saada aimu, milleks neid vaja on.

Teine peatükk kirjeldab täpsemalt Firgelli L12-NXT aktuaatorit, räägitakse lähemalt ta omadustest ja kujust. Lisaks on peatükis ka õpetus, kuidas aktuaatorit roboti külge ühendada. Juures on ka programmeerimiseks vajaliku tarkvara installimine ja seadistamine.

Kolmandas peatükis on toodud struktureeritult 3 ülesannet raskuse kasvamise järjekorras. Iga ülesande juurde on kirjeldatud ülesande tekst, eesmärk, lahenduse idee ja järgmisel lehel ka üks võimalik lahendus. Samuti on Lisa sektsioonis kaasa pandud CD, kus peal on lahendusfailid ja bakalaureusetöö ise.

Kokkuvõttes on tegu ingliskeelse õppematerjaliga, mis on mõeldud isikutele, kes pole varem robootika ja/või aktuaatoritega enne kokku puutunud. Kui lugeja on läbinud materjalid ja lahendanud ära ülesanded, siis peaks tal olema selged põhitõed robootikast, täpsemalt LEGO MINDSTORMS NXT komplekti kasutamisest koos aktuaatoriga.

Sources

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Appendix

A CD with following files:

Exercise1.rbt	Solution to Exercise 1
Exercise2.rbt	Solution to Exercise 2
Exercise3.rbt	Solution to Exercise 3
baka.doc	The paper in digital format