SNAKE-CATERPILLAR HYBRID ROBOT ‘SNAKEBOT’

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Aimed for participation in TuKoKe competition of 2020

Group IV project Learning Diary

Building Snakebot

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Overview of Snakebot

There exist many situations around the world, in which human investigation and control is essential, ranging from maintaining factories in working condition to rescuing human lives in case of natural catastrophes. Often times, such places may prove extremely dangerous or downright fatal for human beings to enter. Our team attempts to solve this problem, by introducing Snakebot, an autonomous scouting robot, with no fear.

Snakebot is a bionic robot that combines the features of a snake, a caterpillar, and a scorpion. It can therefore move in several ways: It can meander like a serpent enabling it to move on sandy and marshy materials that would sink wheels and feet, and it also has caterpillar-mimicking suction- cupped feet, that provide strong adhesion to flat surfaces and allow the robot to scurry along vertical planes and even upside down. Snakebot also has the claws of its arachnid inspirer, which provide an ability to manipulate objects in the environment, potentially allowing the robot to fix certain errors on its own.

It consists of several modules attached one after another using magnets, lending it its elongated shape. The base of the modules is covered with scale like material, that has varying friction coefficients depending on the direction of motion. The rotation of joints between the modules is facilitated by a system of strings pulling certain edges of two consecutive modules closer together. Currently the system has been designed for horizontal and vertical rotations, but the planning of third degree of freedom is under its way.

The friction-material and a hinge system allow for a faithful mimicking of a snake, which works on the principle of compressions and decompressions. This is unlike many of the current snake recreation attempts, that work by building a system of rings that rotate about themselves and essentially propel the snake with a system of many wheels.

Each module, except the head, also have two pairs of suction-cupped feet that can be used in more size constrained places where slithering from side to side is not possible. Additionally, the motion with them is much more precise. In case of meandering, the feet can be lifted to the top position, to allow not disturb the motion.

Each module contains four DC motors, with their torque amplified by a system of gears. Two motors control the string-hinge rotation; the other two – the legs. The motion is measured by inductors, that sense the rotation of magnets attached to gears.

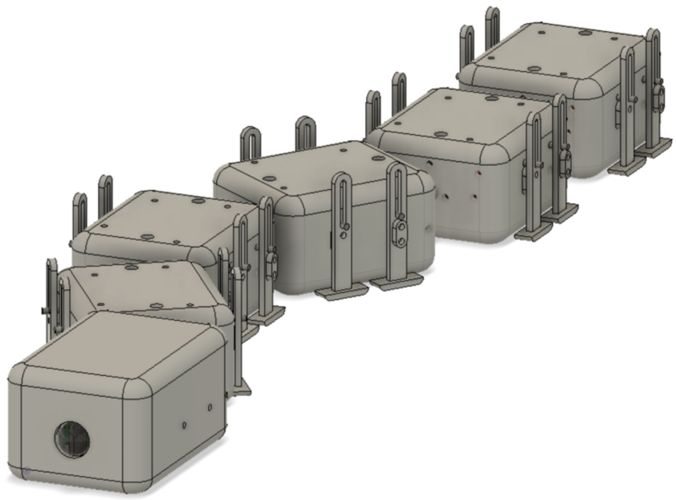
At the heart of each module is the module controller, designed by us, which contains an 8bit microcontroller PIC18F26K22, that receives commands relating to motion from the head module. Each controller controls two dual bridge drivers (TC78H651FNG), that in turn control two motors each. The inductors are connected to the ADC ports of the controller; the controller then measures the induced voltage and interprets the rotations. The controllers of all the modules are interconnected using an i2c bus, which is used in communication with the host controller. Each controller also has some redundant pins for analog input, i2c, and UART, enabling the connection of additional sensors.

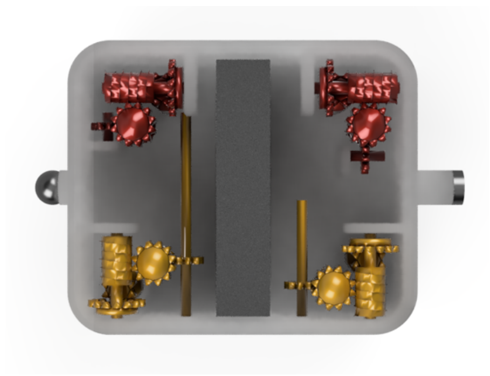
At the front of the Snakebot is the head module, which houses the ‘brains’ of our snake, the NanoPi Neo Air, which is a quadcore 32bit SBC, with integrated Wi-Fi and Bluetooth connections. NanoPi also has a camera connection, which our bot utilises. The head module has space for some additional sensors, such as gas detectors and gyroscopes, in order to collect more data about the environment.

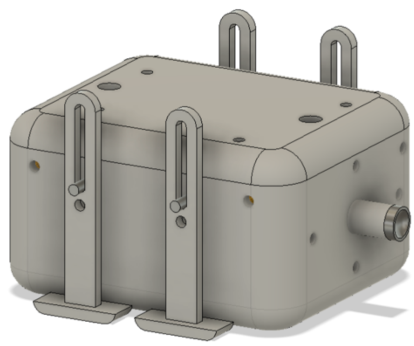
The wireless communication channel is used to communicate with the robot. A controller application on a mobile phone or a computer sends some simple commands to the robot and receives sensor readings.

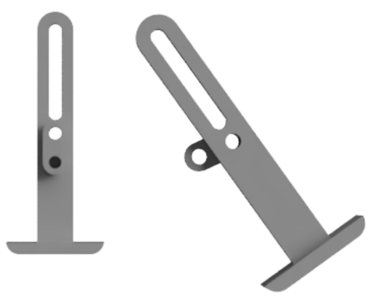
Alternatively, some form of AI could be implemented on the NanoPi allowing for execution of automated tasks.

Snakebot is still a work in progress, with no full model having been yet built. 3D models of the modules have been designed on the computer and 3D printer. The module controller PCB are also ready. Currently we are waiting for the motors to arrive (from China) and are writing the firmware for the module controllers. Our goal is to present a working solution by the time of the finals if we get chosen to them.









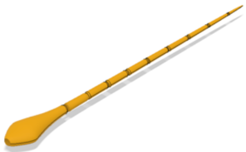
Building Snakebot

Prologue

Hi! My name is Dariya Sivovolenko, I was the initiator of this project, and will tell you how this project evolved and came to life. I have been in this project from the very start and can tell you the full story of how this project evolved and metamorphosed. What started as an individual inquiry, evolved into the (mandatory by the IB) Group IV and absolutely non-mandatory science fair competition project.

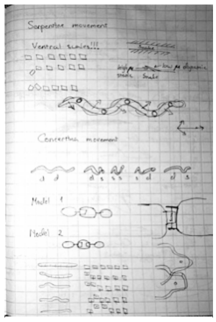
How we got the idea. Valentine joining

Originally, the idea of building a bionic robot came as a challenge in the area of engineering, long before Group IV and any competitions. Being interested in Biology and Mathematics, I was hit by a thought: what is it in a snake's movement that pushes it forward? Can we mimic it? The project started from research into snake locomotion.



Early 3D model of possible design

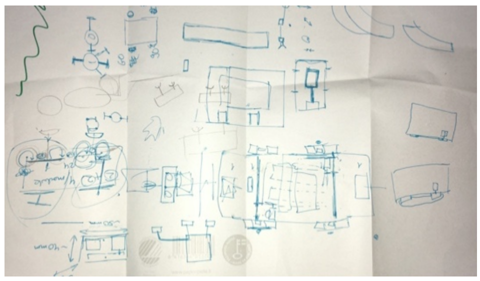
With the start of the new school year, I thought: why not actually build it? I asked Valentine Rainio if he wants to join the project. Valentine is expert in electronics, programming and mathematics. He agreed, and we sat down to try to form a more concrete picture of the future robot. At that time, we had many ideas, a pneumatic tube, driven by variations in pressure; cobra-like segmented tube and many others.



Early sketches of snake locomotion

Version 1. Motor connections. Aaro joining

Together with Valentine we started designing the robot. Then, we realised that the workload of building a snake in time for Group IV is too much for two people. When Group IV officially started, we began searching for those wanting to join us. This is how we found Aaro Järvinen, as it turned out later, an expert in friction material.



Sketches and plans made on the first meeting of the trio.

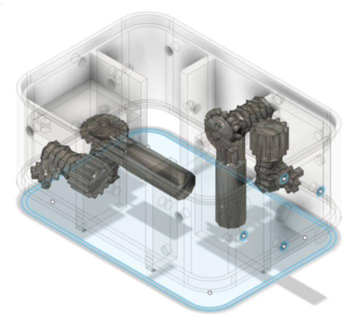
(November)

We met to discuss how we will plan the work. Through some heavy negotiations, the original plan was altered. This was no longer to be a snake, but a hybrid between a snake, a caterpillar and a scorpion. It evolved legs with suction cups to cling to vertical and inclined surfaces and claws to interact with its surrounding. We decided that Valentine is going to find and order electronic components (motors and gears) and send Dariya a 3D model of the gear construction and sizes, who will then create a full 3D model of a module and find a place to print it. Aaro took up the task of designing the legs and their mechanism of motion. We decided we will have the body built up of individual segments, each having four legs, controlled by four motors and interconnected using a system of strings and magnets. This allowed modules to move in vertical and horizontal directions relative to one-another.

Version 2. String connection

(Mid-November)

We did a colossal amount of work. Especially Valentine in designing the gear system. We often heard him joking that if this would have been counted as CAS (extracurricular activity; by IB rules it is mandatory to have a minimum of around 150 hours of CAS), he could have forgotten that word for the rest of the Diploma Program. At one moment we were considering moving this project away from Group IV, so that Valentine could get more credit for his work. But in the end, we decided to merge the two (with allowance from our CAS supervisor).



M1.1. Mid-November version of the alignment of components inside a module.

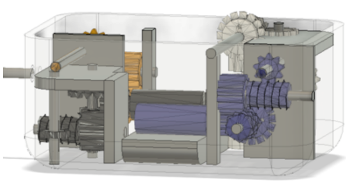
During this time there was constant messaging between Dariya and Valentine about gears. Typical messages included: 'Motor left', 'Motor left corrected', 'Motor left corrected 1' and so on... A typical start of the day was the phrase: 'I tried the design you sent last night; can you rotate the (second) gear by (180° vertically)?'. Meanwhile, we found the exact motors and other components and ordered them. Aaro set out to find appropriate axels.

Printer, printer, printer. Where are you?

At the same time, Dariya got access to a 3D printer. We were lucky that a company specialising in high-tech electronics allowed us to use their super-precise FormLabs 2 printer, which has magnificent resolution. It allowed us to print 2 mm holes and 1 mm walls effortlessly.

M1.1 printed. Our first print on the FormLabs 2

Version 2.1. Choosing motors and electronics. Planning the gears

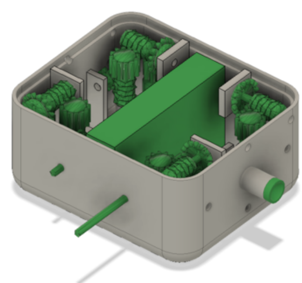


M1.1 arrangement left little space for battery. Too little

Towards the end of November, we realised that, with our current arrangement of motors, we are unable to fit the motors and batteries into one module. We got, and straight away abandoned, the idea of putting motors and batteries into different modules, because we wanted each module to be self-sufficient in power and movement to increase performance of the robot. This meant that Dariya started redesigning the module's axis and motor positions, and Valentine had to change the gear system to make it more compact.

(Early December)

In a few days' time of hard work, the new motor alignment came to light. Compared to M1.1, M2.1 was wider by about 6 mm, and had a vertical positioning of motors. Also, the inter-modular connection was added as well as the battery.



M2.1 Has more space inside. The vertical positioning of motors allows for a big battery

Aaro sets out to reinvent snake scales

From the very begging we understood that in order to mimic snake movement, we need a material which would be similar to snake scales. It needed to have a small coefficient of friction when moving forwards and a very large one when moving backwards. We interrogated the Biology teacher, no result. Out of despair we even framed the question to the Chemistry teacher. In the end our Physics teacher gave us an idea: skis for country skiing function in a similar way. Aaro grew interested in reinventing the serpentine scales.

(Written by Aaro: The story of reinventing snake scales)
First when we started brain storming ideas for a friction surface for the robot, we came across different ideas. We learned that most high friction surfaces require nanotechnology, which unfortunately we could not use. Therefore, we started inventing executions that could be constructed from everyday materials. One of them, for example, considered using a grip that is used in some of the skis. However, when testing its properties, it turned to wear out easily and be too sticky.
Next we took one step back and inspected the skin of the snake again. We believed that mimicking nature and imitating snakes´ scales could prove to be a useful method. When thinking of different high friction surfaces, where the idea of scales could also be applied, we came across patches that are used to repair broken tires in bicycles. After testing it on a model, we decided to use it for its high friction properties.
To secure the junction between the patches that are applied in a scale like structure and the module, we first glued a part of a bicycle´s inner tire to the module before applying the patches.

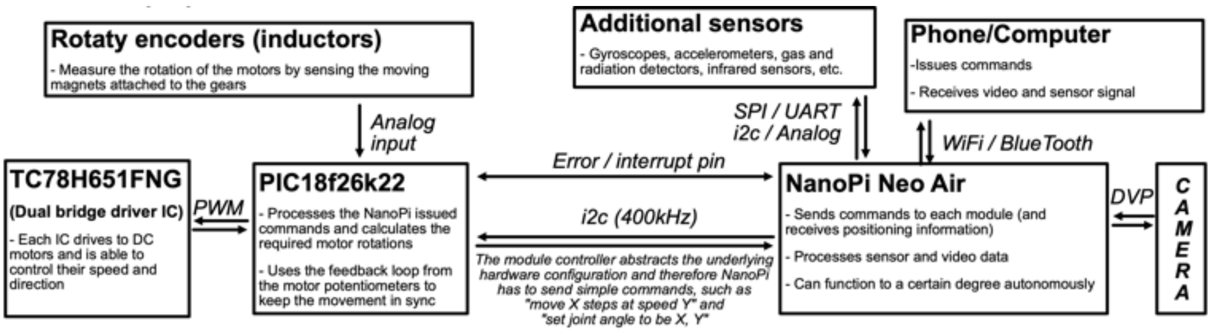
The Nano-Pi & sensors debate

(Written by Valentine: Why amongst all minicomputers Nano-Pi was chosen)
The small size constraints have caused a forage for a suitable microcontroller, which is of small size, but still is of an adequate power. We had to reject Raspberry Pi's as they were too bulky with their USB port, and even the Pi zero is 65mm, far larger than our planned width of the module being ca. 35mm. After a long search we settled with NanoPi Neo Air, which has the size of only 40mm, while still housing WiFi and Bluetooth controllers, and having a connection for camera.
The size constraint also forced us to reject servo motors, though they would have been of tremendous help at managing the modules, as they provide a mechanism for precise motor control. Instead we settled with standard DC motors with us gearing them ourselves and sensing the motion using some rotary encoders. Here we saw two possibilities: to either use inductors or photodiodes. Since I had no idea how inductors worked and believed that attaching magnets to gears would cause too much rotational resistance, I decided to go with photodiodes. The others, however, thought that emitting light would be too much of a power loss, and therefore it was only after some weeks that we finally came to a conclusion to use the inductors.

Valentine plans microcontrollers, everyone else tries to understand what they are

(*Written by Valentine: How was the current scheme of controllers reached)*
Microcontrollers… A myriad of options to choose from, a massive range of features to skim through while selecting the right controller. The bit-width, the memory size, clock speed, everything was under my control.
For me the main criteria were PWM capability for motor control, ADC for encoder sensing, I2C and UART for inter-controller connections, and a high enough clock speed with an internal oscillator, to allow processing of data and a simpler circuitry.
Originally, I looked for a 32bit controller (PIC, for I have programmed them before), for they support more automated peripheral and interrupt handling, but they seemed to mostly lack internal oscillators.

In the end, I decided to use PIC18F26K22, for they were familiar to me from my previous projects and they had an adequate number of pins in conjunction to the features I needed.
This was an easy task compared with finding a half-bridge driver for the DC motor. The problem with them was, that they either had too high of a PD requirement or could not drive enough current through them. I was very grateful in the end for finding Toshiba's TC78H651FNG, though even they had a maximum current drive of only 800mA per motor, while the motor stall current is rated to be 0.95A, and therefore I am not sure whether the connection will work out.



Simplified Interface Diagram of Snakebot control system

We have a robot; how do we control it? Lassi joining

When we neared this phase, it became crucial to start writing actual programs, we realised we need yet a new team member. At the same time Lassi Rainio switched into our year. Lassi has a lot of experience developing video games and programming, he took the job of developing the user interface.

(Written by Lassi: How the User Interface was created)
For our project we wanted to develop an UI that would make controlling the bot easy and effortless. Going forward with developing an android app was a clear choice, as most people already have a mobile phone, and as developing an app is much cheaper than developing a standalone controller. Because of some problems with shipping, we didn't have time to do any testing with the UI and because of that we are still in the concept phase on that front. The app is however developed so far that once we have defined the different commands for the bot, we can almost immediately start testing.

Camera explosion & battery selection. Model again too narrow!

Whilst working with Nano-Pi, the DVP camera we bought, over-heated and burned down. We suppose that there was a mismatch of protocol. This forced us to buy a new camera. This time we decided to play safe and buy the official partner camera. At the same time, the batteries arrived, and turned out to be 48 mm long, instead of the claimed 44 mm. This means that Dariya needed to change the size of the module yet again.

Motors lagging in China

We ordered the motors in the start of November, however by the 21st of January they still haven't arrived, or even left China. Due to this we were unable to start assembling the robot. And in the end cancelled and reordered the motors, this time with a better postal service. All other components ordered have successfully arrived or are in Finland. We ordered inductor sensors for measuring the motor rotations as well.

Designing legs

(Early January)

Up to this point, we really didn't return to the subject of leg movement, focusing on other aspects of the work. But as the competition came closer, we realised that we need to speed this up. We tried many types of movement, trying to find a mechanism, which while being compact, would give us a desired movement algorithm.

Valentine created a simulation and tried many types of mechanisms, trying to achieve the desired pathway. However, we couldn't make it to be compact enough. In the end Dariya had to cut away some parts of it, so the pathway could have been changed. After about a week's time of work, we finally managed to make it fit.

Desired movement pathway of the leg

Programming

The amount of programming to do is immense. Valentine and Lassi decided to split the workload. Valentine is going to build up from the bottom-up (motor-controllers -> microcontroller -> Nano-Pi) on the robot side, and Lassi is going to build top-down (User interface -> Android -> Nano-Pi). This allows for simultaneous development. In the end, we will be able to control the snake through Wi-Fi from an Android phone. In the future, we can even connect a VR headset to the robot, in order to allow the operator to evaluate the situation around the robot better.

Post-school fair development

After the school science fair, judged by university professors, where our project received the 1st place, we found a few ways to improve our robot. First of all, we will get in touch with the University, to try to create our own batteries of specific dimensions, which will allow us to reduce the width of the modules, allowing the robot to move better. One of the judges also turned out to be an expert in the area of nanotechnology, so Aaro will try to get into the University labs to develop a better friction material.

The school science fair also allowed us to practice our presenter skills, and identify the key elements in our presentation, and how it should be delivered.

We are also waiting for the reordered motors to arrive, after which we will assemble the robot and start the post-assemble phase of building and rebuilding.

Links to further information on Snakebot

Link to the concept video:

https://vimeo.com/385991440

Link to the exhibition poster:

https://drive.google.com/file/d/1Ta8zsO2lAfkuAjaK0vNnXPiejzFLR5JO/view?usp=sharing

3D Full robot with legs: https://a360.co/2RzUkyN

3D Full robot (no legs) & animation: https://a360.co/36tTl7D

Additional material:

Links to the 3D designs and animations:

Module 2.1 (44 mm battery): https://a360.co/2PdMWI2

Module 4.1 (University battery, still worked upon): https://a360.co/38P21qJ

Head 2.1 (still worked upon): https://a360.co/34bwfRT

Links to technical documentation of electronics:

Nano Pi Neo Air: http://wiki.friendlyarm.com/wiki/index.php/NanoPi_NEO_Air

Module-microcontroller:
https://ww1.microchip.com/downloads/en/DeviceDoc/40001412G.pdf

Module-motorcontrollers:
https://www.mouser.fi/datasheet/2/408/TC78H651FNG_datasheet_en_20180418-1390165.pdf