Best Practices in Mechanical Engineering
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1. Introduction

Humans are able to do almost everything they want. We are able to move, communicate with each other and if something seems impossible for us, we try to make it possible. For example humans don't have wings, so we can't flutter with our arms or legs, but birds can – It simply isn't in our nature. However, people found many ways to fly by building machines like airplanes and helicopters. If something seems out of our reach, it doesn't mean that there is no way to find a solution.

Without mechanical knowledge life wouldn't be the way we are familiar with.
Mankind is creative, curious and adaptive and this is the reason why our environment changes. The general development is getting more important and so is the support for the today's youth. Kids should be able to enjoy life and learn from their environment. There are so many things toddlers can learn by just watching and touching the nature, so many things you can learn by trying. Learning can be fun, if you do it the right way.

Botball offers you such opportunities. By rethinking a problem, building robots which are able to manage specific tasks, programming them and recording the work participants learn in a hands-on way. You improve your natural scientific skills such as maths, technology and engineering and learn how to work in a team, write documentations and how to manage your time.

Every year the topic of the Botball project changes and every year the given tasks are different. This year's game is called "The Mars Sample Return Mission" or short "The MSR Mission". The game table is space themed and the main tasks are collecting and sorting samples cached by curiosity, loading them into the returning containers and assembling the return vehicles and preparing them for takeoff.

To achieve these tasks and to create two reliable robots we had to improve our mechanical knowledge. In the following pages we are going to go more into details about how we improved our mechanical skills, how we built our two final robots for the European Conference of Educational Robotics as well as how we improved and rebuilt them for the Global Conference of Educational Robotics 2013.

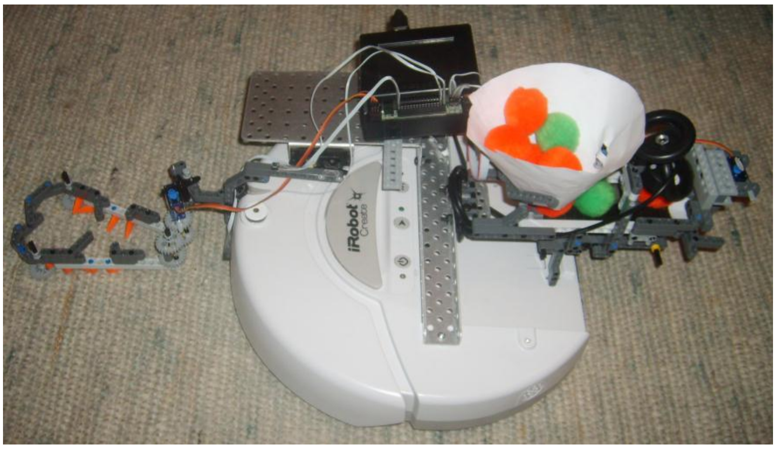
2. Concept and Design

We thought that it might be quite difficult to find a good solution to score many points in the seeding rounds and in the double eliminations in this year's challenge. We thought about many different concepts but in the end we found really impressive and good ones.

There were two outstanding robot concepts which were continuously rethought, developed and tested. In the following paragraphs we are going into more detail. We are going to explain each of our robots, which problems we had to struggle with and how we solved them in the end.

We decided that one of our robots should collect the samples and sort them during the process and that the second one should climb the launch pad poles and stack the rocket booster sections on them.

2.1 Robot Nr. 1 also known as "Tarzan"

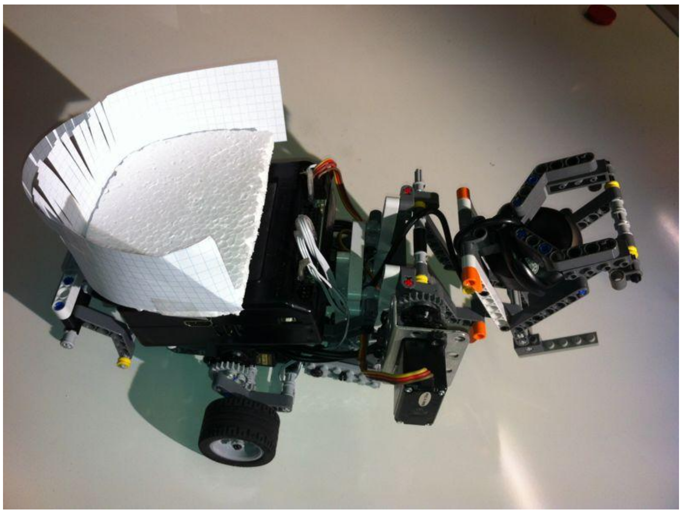


When you hear our robots name "Tarzan" you might imagine a young man, parented by gorillas, swinging from liana to liana. That's the reason why most people think that this name describes our robot which is able to climb very well, but that's not Tarzan's purpose. Tarzan's main tasks are collecting and sorting the poms. You can see a photo of our old robot which we participated at ECER with and as you can see, we used a large claw to collect a whole bunch of poms at once and seperated them using a type of assembly line to split them into 2 piles, one green, one orange.
We had many problems with this concept:

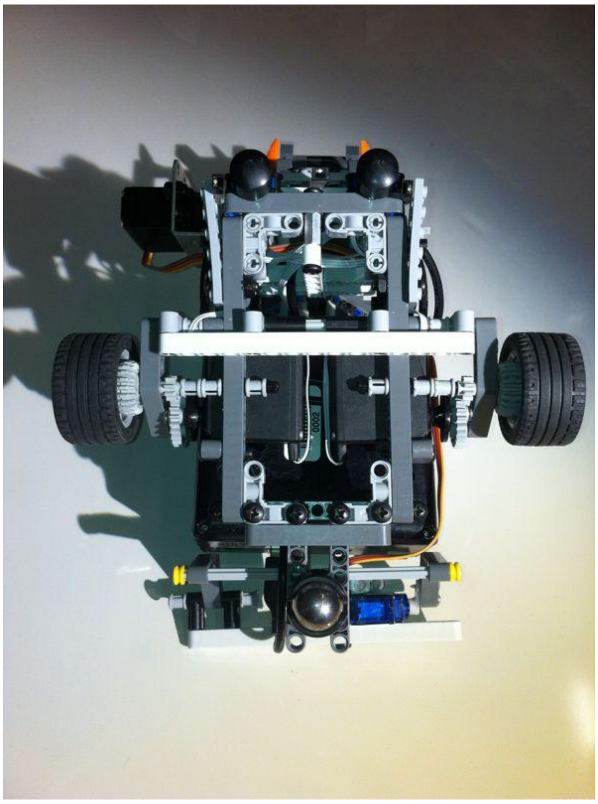
1. The torque on the motor we used to lift the claw was too great so it would eventually cease functioning sometimes.
2. The poms tended to get stuck in the sinkhole so we tried to push them through using a Lego piece mounted on the arm (which kind of failed because it kept throwing the poms out again).
3. It was quite inefficient because the robot didn't know how many green poms were left in the sinkhole so it would just need 20 seconds for 2 bunches.

As you can see, our old concept troubled us quite a lot so we redesigned it.

Here you can see a picture of our new robot. It's an extremely compact built robot mounted on a Lego drivetrain which uses a thing similar to a "foot" to "stomp" onto the green poms. The poms will then be stomped through a kind of "gutter" and be lifted up and roll into a small box mounted on the back of the robot. Using this method, we can utilize maximized efficiency by picking out the green pom, ignoring the orange ones and going right to the next bunch.



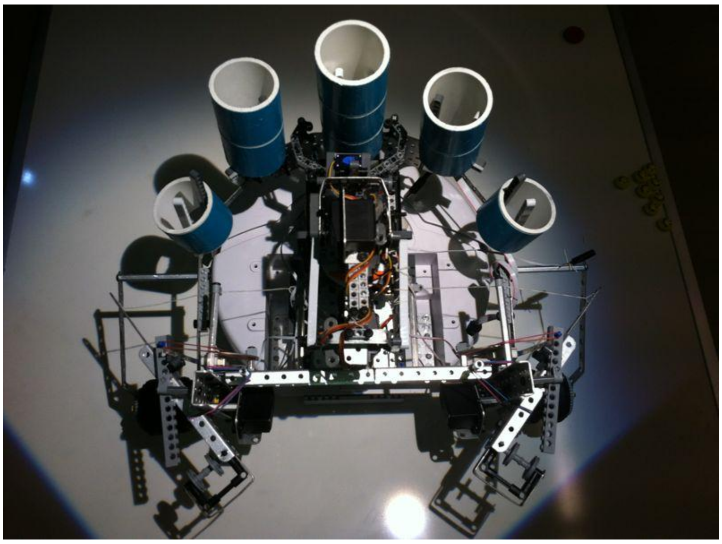
In this construction, the camera is mounted exactly above the "gutter" which makes it possible to easily track the target and aim for it accurately. This way, we can locate the green pom while driving towards the bunch and pick it out when arriving. It reduces the time we need to sort out a green pom drastically. The nice thing about this concept is that it uses only a few actuators. We only need one servo to lift the "foot" and one servo to tilt the transport box and thus can sort and store poms using only 2 servos.



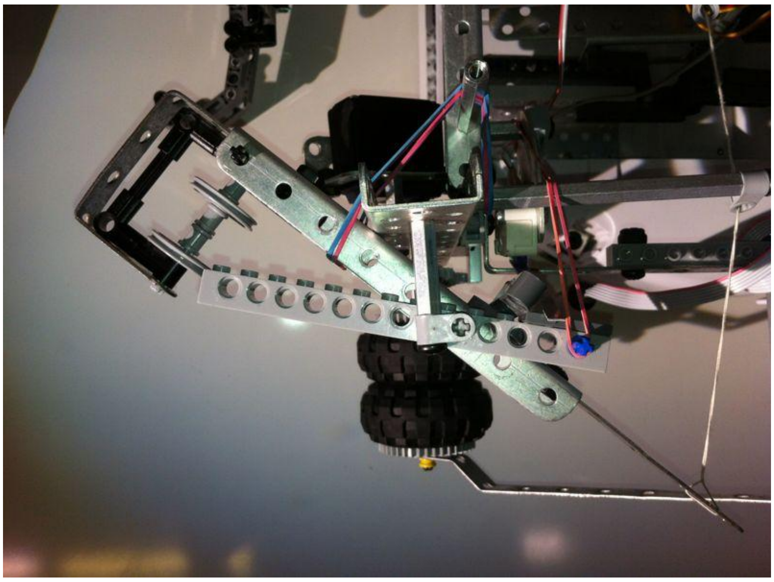
You can see the drivetrain of our robot in the picture to the left. The compact design allows the robot to move very fast and the geared drivetrain gives it a 3:1 transmission. This means that the robot moves 3 times faster but with a third of the accuracy and power. Since the robot doesn't weight that much it doesn't really need the power. The bigger problem is the loss in accuracy. There are 2 types of accuracy losses: slip and "continuous" ones. Slip is when the motor starts turning and the wheel doesn't simultaneously. This is caused by inertia forces and by the gears which do not bite each other properly because they are made of plastic and have quite a bit of slackness. The "continuous" one is the error caused by the motors themself because the two motors one on each side of the robot don't turn at the exact same speed. Although it is multiplied by 3 as well due to the transmission that error doesn't really matter because it's simply like driving faster on the same wrong course as long as it is not driving curves.

2.2Robot Nr. 2 also known as “Jane

We wanted to make a little joke with our robot’s names about the typical gender roles and that is why our robot, which is able to climb, is named “Jane”.



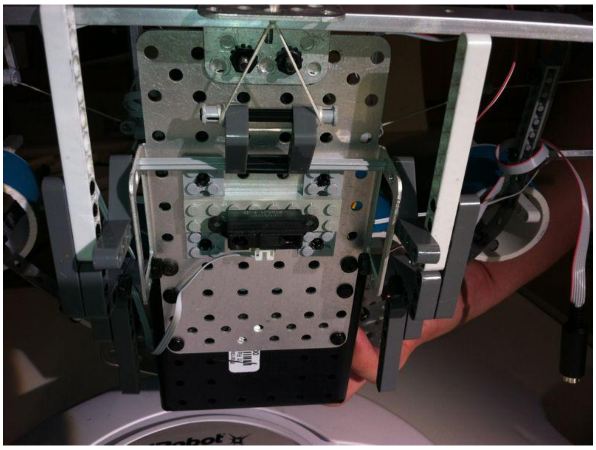
You can see a picture of our robot on the left. It is based on using its own weight to produce a high amount on torque which then gets transferred into contact pressure on the big Lego wheels. Using this mechanism, the robot is nearly able to hang on the launch pad poles without sliding downwards. By using 2 poles for climbing, we can increase horizontal stability as well as grip.This way, the maximum load the robot will be able to carry increases dramatically as well and we actually started to have the problem that the robot was too light without load. The robots actuators are: The “Grabber” which grasps around the pole and is used as the main axis that the robot hangs on and the “Claw” which is used to grab the booster sections and is mounted on an arm with 4 degrees of freedom (3 servo axes to be able to reach all positions and 1 motor to turn the plate which the arm is mounted on to be able to grab things in all 360 degrees around the center axis).



The Grabber itself has a rather complex structure (see right picture). We use rubber bands to pull it open and a rope reeled by a rope winch to close it. By doing so, we can move both at the same time using only one motor and “lock” both at their closed position. It also has a freely turn-able Lego-bar mounted on top, which is again pulled back by another rubber band. Doing so, the robot can lock its position when it has reached the top. The Lego-bar presses a large button when it’s in the locked position and thus the robot can sense the top of the pole using this mechanism as well.

The whole robot is mounted on the iRobot Create (see right picture) which is used for driving on the ground and then "decoupled" when driving up the poles. Because the robot would slide down from the Create, it uses a small mechanism to grab onto rail which it stands on. The mechanism is moved by the same rope winch (see left picture) as the Grabber with the exception that this mechanism opens when the Grabber closes. That's also the reason why the rope winch has 2 levels which are separated by the big black gears whereas they reel the rope in the exact opposite direction.

On the right, you can see the bottom of the main frame of the robot. As you can see, we use the plate which is the main part of the demo-bot. We use the motor mounts as "rails" for the sliding mechanism and the ET-sensor to roughly measure the current height. You can also see the locking-mechanism which is pulled by the string.



3. Implementation/Building Mistakes

Building a robot made of Lego isn't as easy as it might seem. Lego is something you grow up with and something you play with when you are little. But it is also something which can make you exasperate. Implementing our ideas of how the robots should look like in the end isn't easy at some points. You might think of a concept, which would work in theory, but could be impossible to substantiate with the given components. In the following paragraphs we are going into more detail about the mechanical problems occurring during our implementing stage and how we solved them.

3.1 Tarzan

We had rather little problems building this robot. The greatest one was getting so many parts in a compact form. We didn’t use the demo-bot frame since it takes up quite a lot of space and leaves some distance between the left and right motor. It also makes it quite hard to fit a transmission on it so we built our own little frame made out of Lego (See drivetrain picture in the upper section). The rather tricky part was mounting the camera right above the gutter without it blocking the path of the pom when it slides downwards while the actuator is turned upwards by 180 degrees. Thus we separately started building the drivetrain and the actuator which made connecting them rather hard but in the end we managed.

Another problem was stabilizing the wheel axes because the wheels stick out quite a lot. The reasons why are the gearing and the bars which holds the gears of the transmission together. We solved this by making the axes longer and putting them through multiple holes. The robot still “hangs” on the wheels a little but it’s far better now and only remains as optical problem.

We use the small mini-servos to tilt the transport box and since the given Botball set doesn’t include parts, which would make it easy to attach the small servos, it was rather hard. In general it is quite difficult to find a good way to mount the little blue things. During completion of the robot this was one of our biggest problems. In the end, we jammed it between two Lego parts. Till we found our final concept for realizing this we had to think about which components are best to use and which would withstand the strain.

At first, the tilting mechanism was mounted on a big structure built from the cross-like Lego-bars. It was rather unstable and fell apart easily so we changed it to a more stable construction which turned the whole box rather than only opening the back of the box. Since the box is constructed using foam board, it is really lightweight and doesn’t need a lot of force to be tilted.

3.2 Jane

Our first concept of Jane required more time than the concept of Tarzan needed. Finding a way that a robot made of Lego is able to climb such heights is not an easy task and pushes the physics to its limits. We were sure, that we wanted to put the booster section on the middle launch pad since that scores the greatest amount of points, but we had no idea how to do that.

The first concept was a construction which should be able to hold itself on one launch pad and drive upwards. But the wheels of our prototype couldn't produce enough grip for taking something that heavy upwards. We had to rethink our concept and so the second version of Jane was created.

We build a really big robot which was made of all steel parts and hardly used Lego parts from the Botball set. It was able to encompass itself on the second and fourth launch pad at the same time so it had enough stability and more grip. The main idea of this concept was to utilize the high weight of the robot for clinging on the launch pads.

During the building process we used up most of our Lego and metal parts and this was the reason why we had to rebuild the robot using less components. The main idea remained in broad outlines, but the way of building had to change. Otherwise we wouldn't have enough parts to build a second bot.

The clinging mechanism was one thing we changed over and over again. We tried out which of the given wheels would cause the most grip, so that the robot wouldn't slide down the pads. Our team experimented with using rubber bands so that the clinging mechanism would gain more power.

To put the booster sections on the launch pads we had a lot of great plans, but no idea was able to implement so we had to develop something convertible. First we thought about a construct like cranes use it. The crane we build would be moveable in any direction so we could reach every booster section placed behind Jane's drivetrain.

The first implementation was unrewarded because the crane wasn't strong enough to put the booster sections back on the launch pads. We tried to resolve that problem by adding an attachment for the booster sections, but it didn't work out the way we expected it. We had to rethink this concept.

The new structure is now able to turn 360° and additionally had an extendible arm with a grabber on it, which makes it possible to load the launch pads.

Another problem was driving on the gametable. At some point, the robot easily climbed the poles with a load of 16 booster sections but it wouldn't be able to drive on the ground because of the bad balancing and the high distance between the wheels. That made it really inaccurate even though it was moving really slowly. We thought of a solution and that's the reason why the climbing robot is now mounted on the iRobot Create. We also added a 1:3 transmission since the motors wouldn't be able to drive at full speed while climbing anyways.

It is difficult to mention every problem we had developing Tarzan and Jane. But after spending so much time on building and rethinking realizable ideas, it is kind of hard to remember every confrontation we had. We struggled a lot, but human being learns trough making mistakes and so did we.

4. Conclusion

When we now look back at this year's Botball challenge, we have to admit, that we learned more about mechanical engineering than we expected. In comparison to the last season to, this season our main focus changed. Last year our focus was oriented on writing code for our robots. This year we spend less time on programming and more on the mechanical aspects of the robots.

There are many ways to approach a problem and there isn't such a thing as the best solution. You can only find possible solutions but each one has pros and contras. The important thing is to combine many solutions to create a new one while adding their pros and canceling their contras. That's the way we found our solutions by trying, failing and in a continuously improving circle of rebuilding. And even though this document only lists two pages of building mistakes, we could probably write tens of pages about the many failed concepts

We experimented with different textures such as rubber band, rope and paper. Last year we knew that the use of these materials was allowed but we never considered the use. We adapted our ways of thinking during the building process and this helped us finding solutions for our problems. We talked a lot about functional principles we know from vehicles and mechanisms we knew and discussed if they might help us developing our robots.

We improved our technical understanding by adding all of our ideas to our mechanical knowledge. Without this, we wouldn't have managed to build Tarzan and Jane and we wouldn't be able to take part in this year's tournament.