Center for robotics
Physics-Mathematics Lyceum 30

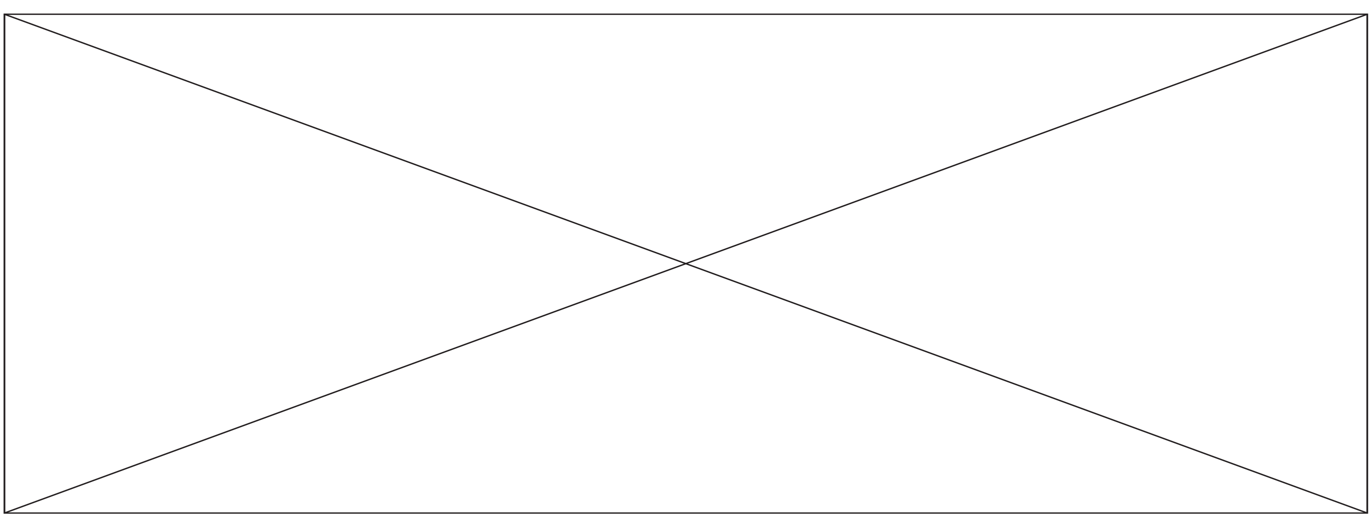
Engineering book of
Competition First FTC

Team PML30 –X

Saint-Petersburg, Russia
2015-2016

1 Team PML 30 X

Team PML 30 X was assembled in September 2014 in the Russian city of St. Petersburg from 3 novices and 2 participants with experience. Tasks and roles were distributed among the participants, and we established safety rules. In the first place the team put spreading principles of gracious professionalism to others. All decisions were made collectively inside team with discussion to find the most optimal solutions. During the year we took part in many events and everywhere we have tried to attract attention to our team and encourage people to take part in FTC. Also we pursued and distributed the principles of honorable professionalism. Talking to the press, we hoped to attract more attention to our team and to the competition in general, as well as attracting sponsors. The latter was important because of the need for funds - purchasing materials and equipment costs a lot. Last season the team took part in the three qualifying competitions, in the regional finals, in European championship and in the World championship. In all of them we made new contacts, shared experience and provided mutual assistance to other teams. In the first qualifying rounds in Sochi we met Stuy Fission 310 from USA and maintain contact with them to this day. On regional finals, we met with a team from Romania, Auto Vortex, and keep in touch with them through Facebook. Also, there is an active group chat with a large number of Russian teams. You can find the team page in Facebook at the address https://www.facebook.com/pages/FTC-team-PML30-X. To increase the efficiency of our team work we used the version control system GitHub, which allows the entire team to work simultaneously on a single projects without losing files and providing easy way to resolve roblems. Also for writing technical books we been used professional typesetting system LaTeX.

[H] 

1.0.1 Instructors

:

Luzin Dmitry
Head of Robotics Department in Phys-Math Lyceum 30, Saint-Peterburg, Russia. Main coach of FTC team.
Information: 26 years old, in robotics 6 years, in FTC 4 years.

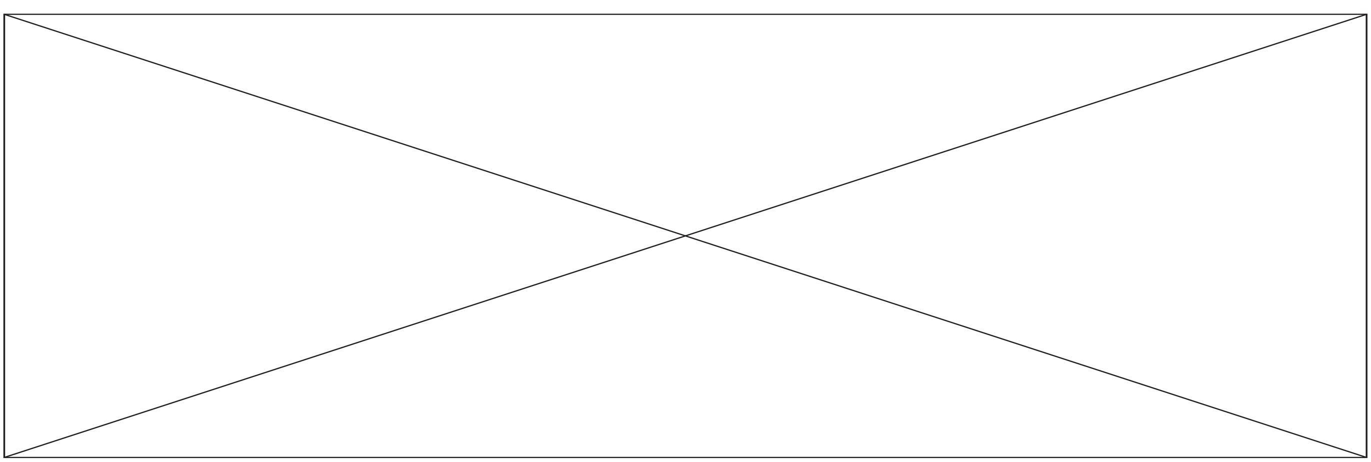
Luzina Ekaterina
Professor of Robotics Department in Phys-Math Lyceum 30, Saint-Peterburg, Russia. Tutor of FTC team.
Information: 26 years old, in robotics 6 years, in FTC 4 years.

Fedotov Anton

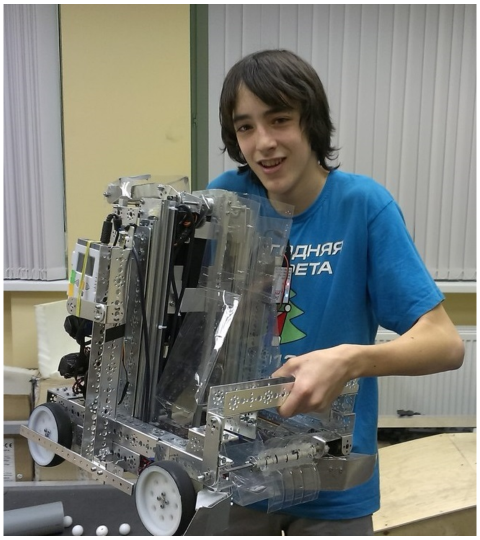
Professor of Robotics Department in Phys-Math Lyceum 30, Saint-Peterburg, Russia. Tutor of FTC team.
Information: 23 years old, in robotics 5 years, in FTC 4 years.

Krylov Georgii

Professor of Robotics Department in Phys-Math Lyceum 30, Saint-Peterburg, Russia. Tutor of FTC team.
Information: 18 years old, in robotics 4 years, in FTC 4 years.



1.0.2 Team members

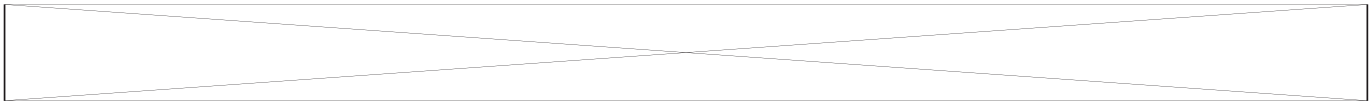


Maksimychev Evgeny
Role in team: captain, operator-2, responsible for the technic of safety, writing of engineering notebook, developer of lift and bucket for scoring elements.
Information: 16 years old, in robotics 3 years, in FTC 2 year.
Why I chose FTC: "This is an interesting project that allows to implement some innovative solutions. In addition to the skills of designing robots, we also obtain the skills of the technical documentation and communication with colleagues which makes this competition as close to real engineering problems."

Timur Babadzhanov
Role in team: operator-1, developer mechanism for scoring autonomous climbers
Information: 15 years old, in robotics 2 years, in FTC 1 years.
Why I chose FTC:" It was recommended for me. Also I heared about previous seasons of FTC and decided that it will be interesting for me. Also I wanted to learn working with TETRIX that can be useful for my projects."

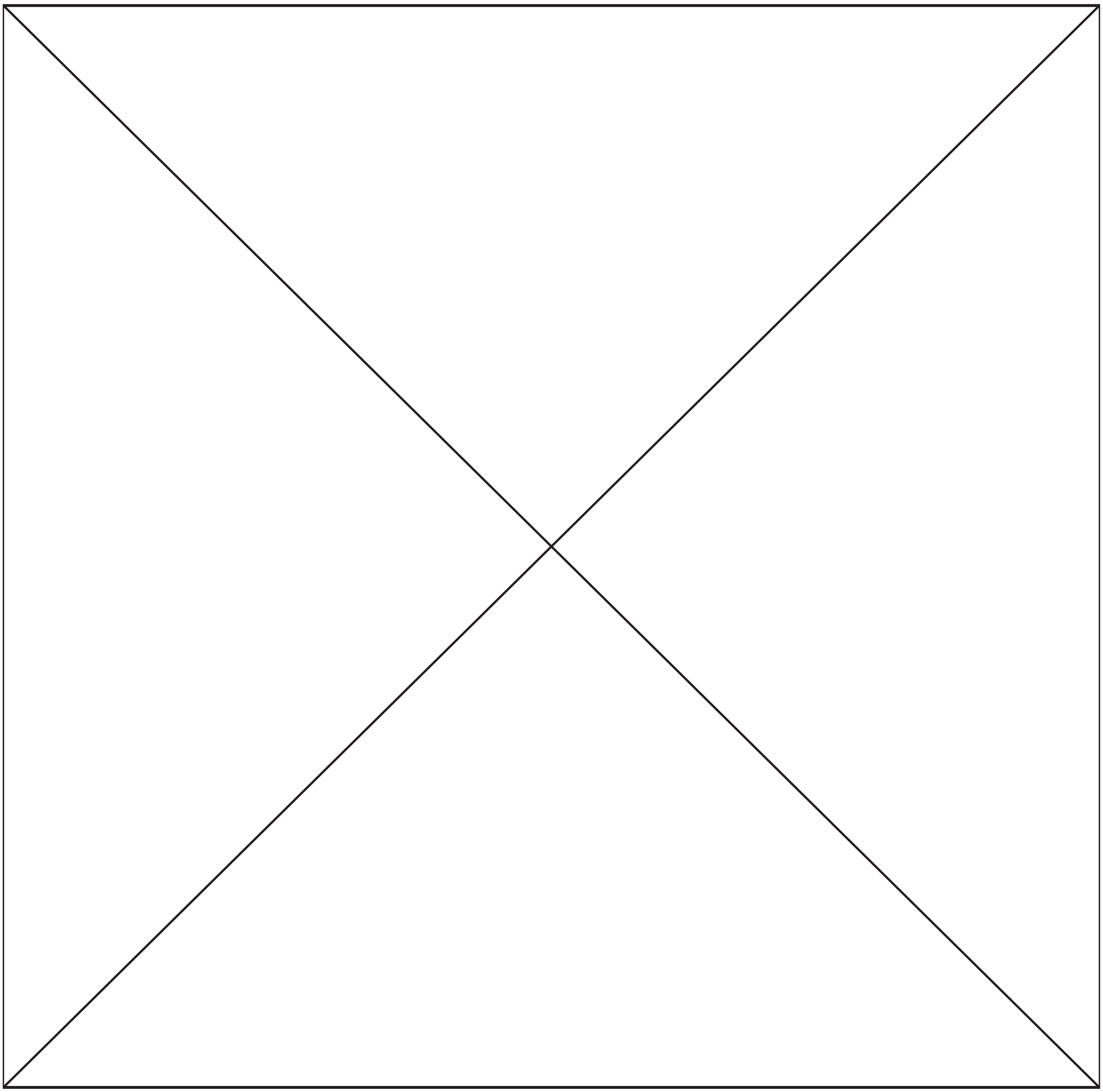
Ivan Afanasev
Role in team: developer of gripper for debris
Information: 16 years old, in robotics 2 years, in FTC 1 years.
Why I chose FTC:" It is a good realization of my engineering skills. I'm good at physics and programming and decided try robotics as merger of this subjects. FTC give opportunity to learn, meet with people from other contries. It is good for pupils such as I."

Victoria Loseva
Role in team: developer of wheel base
Information: 17 years old, in robotics 2 years, in FTC 1 years.
Why I chose FTC:"I enjoy working on new and unique projects, and FTC is a great way for me to do exactly that: solving the challenging problem of building and designing a robot from scratch, as a team, is all it's about!"



2 Annotation

- Our engineering notebook consists of several sections. The main is "Engineering section". It consists of section "Brainstorming". Here is description of actions that robot should can do. Next section is "Strategy" and "Concept". After that there is a section "Elaborating robot". Here is description of designing each module, variants that were looked, how we choosed the best and describtion of all calculations. The next is "Team meetings and events". Here is wrote about process of assembling robot, problems that we found during it and how we solved them. Also in this section described team events such as competitions. In addition there is sections "Team" and "Thanks and prospects"
- Firstly you should read "Strategy" and "Concept" then "Elaborating robot" and after that start read "Team meetings and events".



Contents

3 Engineering section

3.1 Brainstorming (21.09.2015)

Time frame: 21.09.2015 17:00-21:00

Preview: Since this year FTC rules were published, every member of our team had carefully read them. Today we gathered together to discuss all the aspects of this year gameplay and think of how to get on with the most significant features of the game.

General aspects:

Features	Solutions	Label
Moving to the ramp is essential to achieve high score.	Robot's wheel base should be good at moving on the ramp.	chassis
Space between each two bars in 3-rd zone is wider than the standard TETRIX wheel diameter.	Using tracks or 3-4 wheels from each side of the robot will prevent robot from getting stuck.	chassis
It will take a lot of time to climb to the 3-rd zone of the ramp.	It is possible to deliver debris to the highest goal with elevator standing on the 2-nd zone instead of climbing to the 3-rd.	elevator
Goals for debris have a very little capacity.	It is more preferable to collect cubes than balls. That's why we need mechanism to prevent balls from collecting.	gripper
Pulling up costs 80 points. It's not difficult to realise then.	At least 1 DC motor should be reserved for pulling up. It is possible to grasp the pull-up bar with hook and lift to it by reeling the cable.	pull up
Moving over the inclined plane and pulling up require high moment on motors. However, the number of motors is limited.	Robot should be light enough to decrease the moment required for moiving and, as a result, increase speed of moving.	weight
All the zones of red alliance are the mirror reflection of blue alliance's zones.	Robot should be symmetrical and capable of playing on both sides of field.	concept
Robot can grip 5 debris at once, when the maximal capacity of one bucket is 24 cubes. So, to fill one bucket robot has to repeat collecting and taking cubes to the goal 5 times per 1,5 minutes	Gripper for debris should be at the front side of the robot and extractor for scoring elements - from the back side. It will allow robot to go to the ramp backwards, so it won't need to turn around on the ramp before going down to collect debris. It will save some time.	concept
It's quite unconvenient to exchange ramps with your ally during the game.	We will negotiate with our ally about spheres of influence before each game. Additionally, there should be two autonomus programs for climbing onto both ramps.	strategy
The only main difficulty of this year autonomus period is that both robots in alliance have to fulfil the same tasks at the same place. So, there is a high risk of collisions between them.	A number of different programs for autonomus period are needed for easier adjustment to the ally's strategy.	strategy
It's not restricted to collect debris in autonomus period.	It will be useful to realise automatic collection of 5 cubes in autonomus period. At the conclusion of autonomus period the robot will remain on the ramp with 5 cubes and we will put them to the goal immediately	strategy

Detailed explaination:

1. As we know from our previous FTC seasons experience, there are strict constraints for wheel bases can be used for climbing mountains. Firstly, omni and mechanium wheels are completely not suitable, because mechanium wheels can ride only on plain surface (when 2-nd and 3-rd zones have cross hurdles) and omni wheels have ability of undependable movement on small rollers so they behave very unstable on mountain. Various conbinations of standard and omni wheels can't be used too, as in the 2-nd zone there are obstacles which can cause some wheels lose contact with ground and if the rest of wheels will behave differently, the whole robot would be unstable. In conclusion, we can use only standard wheels

or tracks.

Additionally, wheel base should be symmetrical against central axis for stable climbing to the mountain. If we decided to climb 3-rd zone with standard wheels, we will have to put 3-4 wheels at the each side to avoid getting stuck on hurdles (the space between two hurdles is for about 14 cm, when the diameter of big TETRIX wheels is only 10 cm).

2. To score in high zone goal from 2-nd zone robot should have a mehanism for delivering debris to the distance of 40 cm or more. Shooting debris is entirely unsuitable approach, because it's impossible to realise enough accuracy for stable scoring cubes and especially balls. Another way is elevator. There are three types of lifts which familiar to us: they're crank lift, scissor lift and retractable rails.

   Scissor lift is not suitable for this year competition, because despite it's main advantage - the ability of extracting the longest distances of all - it's too difficult in development.

   Crank lift allows to vary the angle of turning of each segment. However, it requires at least one DC motor of strong servo for every joint.

   Retractable rails can only move along one axis. However, they require the least space and can be equipped by one DC motor (as all the motors are connected to the only reel, which winds the cable).

3. The parameters of the box are $9 \times 5.75 \times 6.25$. So, it can contain at most 24 cubes (4 in length, 2 at width and 3 in depth). As for balls, there can't be scored over approximately 10 of them because of their unconvenient shape and ability of top balls to roll out of the box (especially from the upper box, which is turned on $50°$ from horisontal position).

   This is the reason to implement mechanism for separating debris into cubes and balls. However, there are only 50 cubes on field (12.5 for one robot), so they will run out quickly, so the ability of collecting balls is required as well.

   Additionally, we need to think of how to put cubes into boxes gently so as they will settle down in straight lines. It will allow entire filling boxes with cubes.

4. Solid constructions for pulling up will be too bulky because they have to be strong enough to withstand full weight of the robot. The more reliable and simple solution is steel cable with hook for grasping the bar on it's tail.

   In second case the most difficult objective is to deliver hook to the bar, which can be solved by creating secondary lift for it (the main one is a lift for debris). Mechanism for shooting hook towards the bar is not suitable as it can be dangerous for operators and spectators (if the it will be accidentally activated during the match).

5. The main weight of the robot goes the battery and motors. The weight of the battery is 570g. We have two types of motors: standard TETRIX motor (207g) and "NeveRest 40" motor by AndyMark (334g). The complete control system (phone + controllers + power distributor) weigh about 700g.

   Therefore, total weight of essential components varies from 2926g to 3942g (with 8 motors). With several beams (166g the longest), wheels (117g each) and other construction elements robot will weigh from 6 to 10kg.

   In our primary calculations robot's weight will be accepted as 10kg. However, it is preferable to make robot as light as possible.

6. Wheel bases which are good at climbing mountains are usually less manevrous, than carriages with omni and mechanium wheels. This way, the less robot will turn, the more effective it will compete.

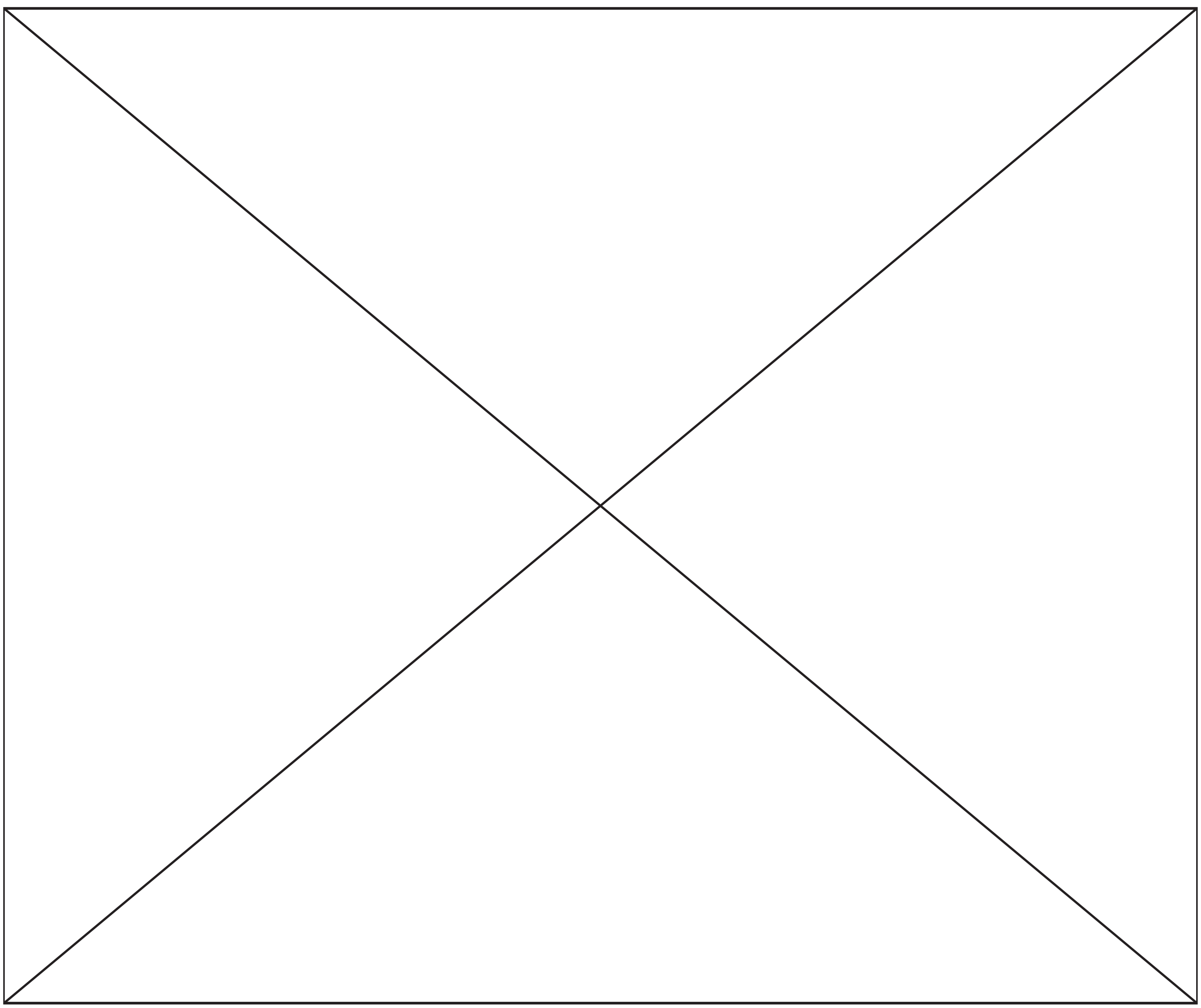
   Accordind to this, it will be more convenient to realise construction that will allow robot to score debris without turning around. Robot can collect debris with gripper on it's front side while moving forward and then go backward to the ramp and score debris with the mechanism on it's back side.

   Furthermore, it will be useful to attach one robot to one ramp in order to prevent them from commiting extra movement. Although it seems that two robots can fill the top goal together two times faster, in fact they will just interfere with each other. So, it will be a good tactical step to negotiate with our ally before the mach which robot will operate with each mountain.

7. This year field is symmetric with respect to the diagonal. It means that all zones of one alliance are the mirror reflection of another. Consequently, the gameplay depends on which alliance you are playing for.
   So, the robot should be capable of executing equal tasks playing for each alliance. The major unconvenience cause releasing alpinists, as it requires two similar mechanisms from both sides, that will take 2 servos instead of 1. Mechanism For scoring debris should be summetrical to provide filling boxes from both sides of the ramp. Besides, autonomus program should be twoside as well.

Additional comments: For the next meeting we need to think of two issues:

1. which tasks our robot should be able to execute without loss of efficiency
   and
2. to set the priorities of performing tasks during the game.



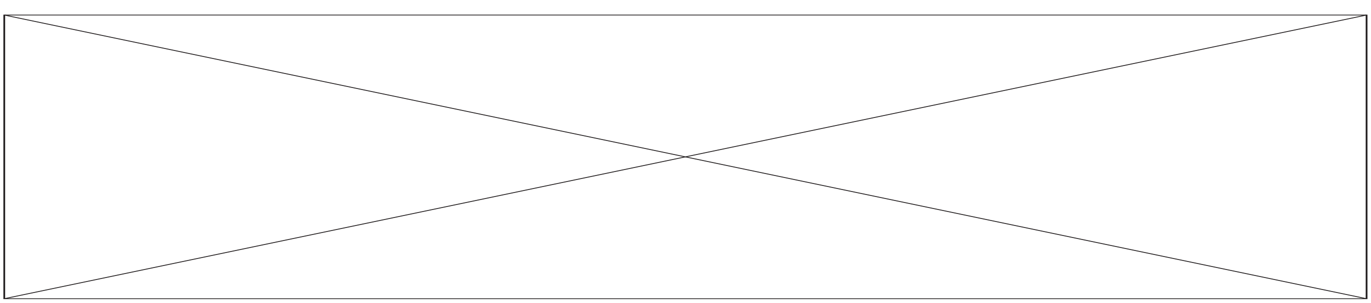
3.2 Strategy discussing (22.09.2015)

Time frame: 22.09.2015 17:00-21:00
Preview: Today we put the priorities during the building of the robot and performing tasks of the game.

Detailed explaination:

1. The tasks which robot must complete (We assume that robot can do everything. Tasks located in order of priority) :
   1.1. Autonomous period:
      1.1.1. Push the button and score climbers. It give 60 points (20 - button 10x2 - climbers in autonomous 10x2 - climbers in tele op).
      1.1.2. Ride to opposite mountain and collect balls and bricks. It help us to save a time because when start tele op we already have 5 bricks.
      1.1.3. Go to middle or high zone of the mountain. It give 40 (or 20) points. Additionally, we start driver control period near the top box. So we can put 5 bricks there immediately.
   1.2. Driver control period:
      1.2.1. Put elements that we collected in autonomous period to the top box.
      1.2.2. Go from the mountain and collect 5 bricks. We decided to collect only bricks because the balls take up much space in the box. So if we collect only bricks we can put more elements to one goal and get more points.
      1.2.3. Put 5 bricks to the top box. After that the top box most likely will be full. So we won't be able to put another five bricks.
      1.2.4. Collect and put 5 bricks to the middle box.
      1.2.5. Start moving to the crossbar and score climbers.
      1.2.6. Turn "all clear" signal.
      1.2.7. Pull-up.
2. Implementation of robot that can perform following tasks (tasks are in order of priority)
   2.1. Stable scoring to the middle box. This task is very simple and give a lot of points.
   2.2. Scoring to the high box. This task is more complex but gives more points.
   2.3. Releasing the climbers on the rope in driver control period. We can do it very fast and get 60 points but for scoring the top climber we must be able to climb to high zone.
   2.4. Scoring climbers in autonomous period. It is very easy task that give 40 points (as 4 bricks in the middle box).
   2.5. Riding to the high zone. It can give 40 points in autonomous period and 40 points in tele op.
   2.6. Pulling up. This task give the most number of points.
   2.7. Turning "all clear" signal. It gives us 20 points and our opponent lose 20 points.
   2.8. Pushing button. This task is difficult in terms of programming and gives only 20 points.

Additional comments:Task for the next meeting: to elaborate concept of the robot.



3.3 Concept discussing (24.09.2015 - 03.10.2015)

Time frame: 24.09.2015 - 03.10.2015
Preview: Objectives for current session are developing the concept of the robot and

Conclusive solutions for modules:

The main idea that we held during elaboration robot that it should be simple and reliable. Also it was decided to concentrate on the scoring debris to boxes and complete this task as well as possible. So we refused from the completing the hardest task - pulling. If our robot will score debris very well we'll get lots of points even if we'll not be able to pull. **Days inside session:**

3.3.1 24.09.2015

Time frame: 17:00-21:30
Preview: The main purpose for current meeting was to figure out how the modules of the robot should look and how they will work.

Module	Solution	Label
Wheel base	6 standard wheels with 6 DC motors. The center of gravity is between second pair of wheels; corner wheels are equidistant from the center of gravity.	chassis
Heaviness	Robot should be as light as possible to afford gear ratio for speed 2:1 on drive motors.	chassis
Elevator for debris	Crank elevator with one degree of freedom.	elevator
Bucket for debris	Bucket with turning cover which will close entry inside the bucket to prevent scoring elements from accidental falling out	bucket
Slopes for collecting debris	To increase collecting area on both sides of the bucket will be placed slopes	gripper
Separator for debris	Turnable beam before the bucket, which prevents balls from getting into the bucket in it's lower position (5cm from floor).	gripper
Scoring autonomous climber and pushing button	F - shaped beam	climbers + button

Detailed explaination:

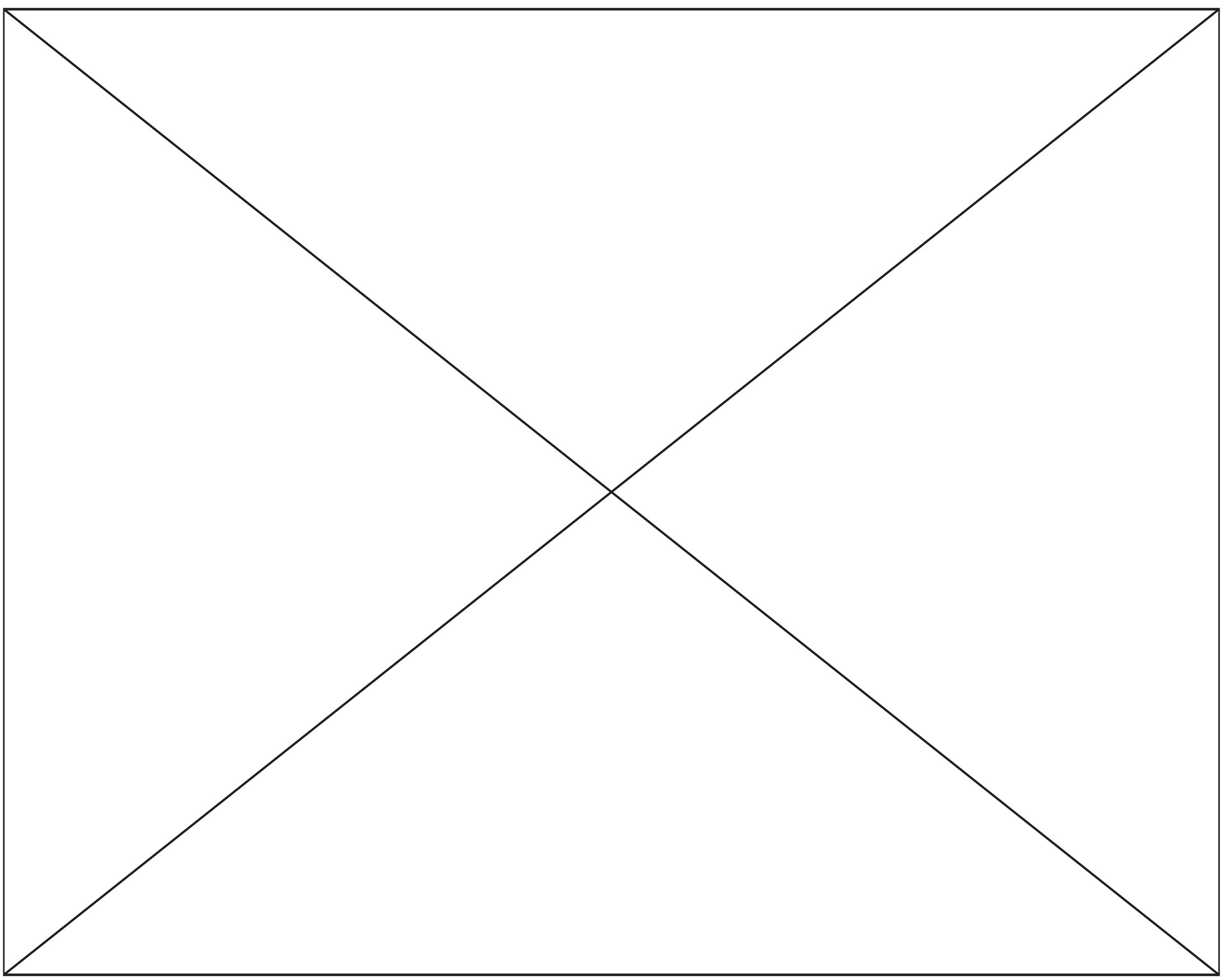
1. Wheel base includes 3 pairs of wheels. The middle pair of wheels provides better rotation, because the their direction corresponds with tangent of the circle of rotation.
   The center of gravity should be on the crossing of lines which link opposite wheels. wheels on one side should be placed on one line. In this construction each wheel will obtain $\frac{1}{6}$ of robot's weight and moments on all wheels will be the same.
2. Both standard TETRIX and "NeveRest 1:40" motors have moments around 10 kg/cm. The diameter of standard wheels is 10 cm. So, the moment on wheels will be $\frac{10\text{kg}\cdot\text{cm}}{5\text{cm}} \cdot n = 2n\text{kg}$ (n - number of motors). Moment required for climbing to the ramp is $10\text{kg} \cdot sin 30° = 5\text{kg}$. Consequently, 3 motors will be enough for driving robot of 10kg to the 1 zone of the ramp. It's possible to use 6 motors with gear ratio 2:1.

3. The crank elevator is the most reliable construction. One rotating beam requires 1 DC motor.

   The moment of DC motor should be enough for moving bucket with 5 scoring elements at a lever of about 40-50 cm. Moment of 5 cubes (250g) is $0.25\text{kg} \cdot 50\text{cm} = 12.5\text{kg} \cdot \text{cm}$. Moment of bucket will be about 10kg as well. So, it was decided to use gear ratio 1:3 (it will increase motor's moment to 30kg*cm).
4. Bucket will be made of PET. PET is the best variant because of it's little weight (weigt of $100 \times 100 \times 0.5mm$ sheet is 7g) and flexibility. This plastic is limpid, so it will be possible to watch how much debris inside it.

   Bucket will have special cover for retaining deebris in the bucket during turning of beam with bucket towards the goal.
5. Slopes will be mounted to the carriage. They will be placed on both sides of the bucket entrance and will lead debris from corners of capturing area to the center. Additionall, they will protect wheels from debris (wheels can get stuck on debris).
6. For scoring climbers and pushing button in autonomous period it was decided use F-shaped beam that turn by servo. When it turn climbers fall to goal from the bucket that fixed on the top beam and bottom beam push the button.

Additional comments: The next meeting we will continue developing concept.



3.3.2 26.09.2015

Time frame: 16:00-21:30
Preview: The purpose for current meeting was to develop ideas were invented last meeting.

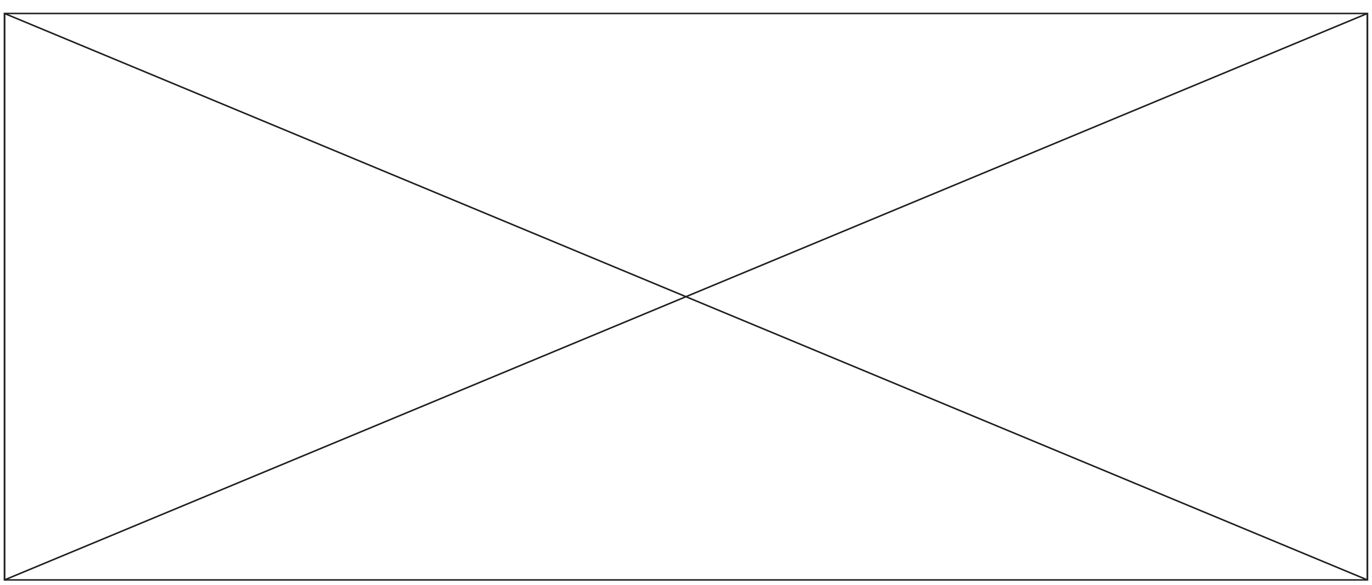
Modules:

Module	Solution	Label
Bucket for debris	The shape of bucket should form one stage.	bucket
Debris separator and lock for bucket	Flap above the enter.	bucket
Crank elevator	There were calculated basic parameters.	elevator
Gripper for debris	Axis with 2 rotating blades ahead of the bucket for grabbing debris.	gripper

Detailed explaination:

1. Today was held a research on how to score debris into boxes in with maximal efficiency. Due to experiment it was revealed, that scoring cubes one-by-one won't allow to score a lot of elements because they will settle down randomly. It was discovered, that the best solution is to put 4 stages with 5 cubes in each one. Cubes in stage should be placed as 2+2+1. According to this researches, the shape of the bucket for debris should form one stage.
2. Today was invevted one possible construction of separator for debris. It consists of axis with a flap above the bucket's enter, which can narrow it's height so as prevent balls from scoring. It will also prevent debris from falling out of the bucket while it's overturnded. This way, current mechanism will be a separator and a lock at one time.
3. Gripper is a rotating brush for collecting debris. It will be used for faster collecting of the debris and also for retaining it in bucket (without gripper debris can freely escape the bucket when the robot moves backward). Gripper should be powered by 1 DC motor or 1-2 powerful servos to be fast and powerful enough. Using 2 blades at an angle of 180° is the most convenient solution as it's simple to realise and it requires less space than construction with 3 blades at an angle 120°.

Additional comments: The next meeting we need to revise all the aspects of concept and correct it.



3.3.3 28.09.2015

Time frame: 17:00-21:30
Preview: The purpose for current meeting was to revise all our previous ideas and reveal weaknesses. Then correct concept.

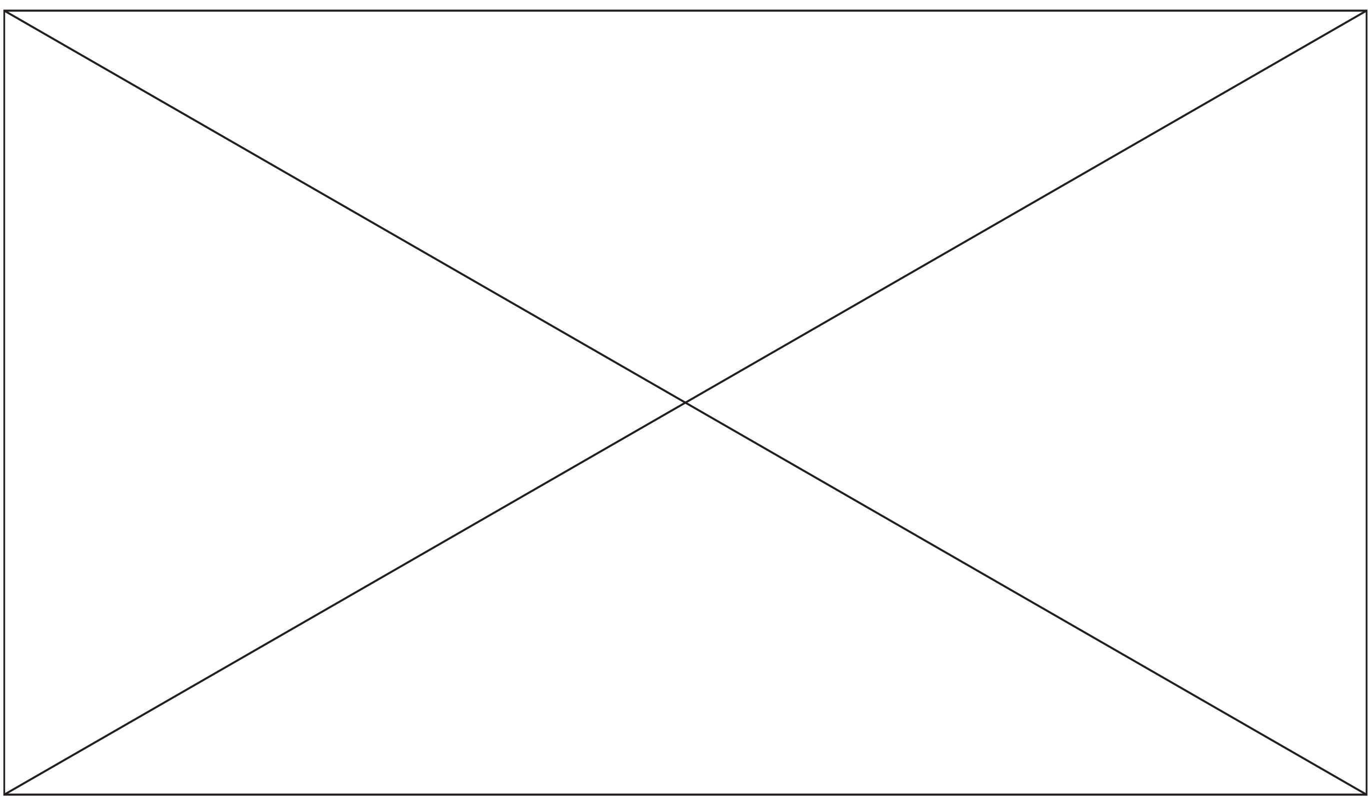
Weak points

Weak point	Solution	Label
Gear ratio 2:1 on wheels can be not enough for climbing	It will be installed gear ratio 1:1 at first. If tests of gear 2:1 will be successful, it will be installed on the robot.	chassis
Shape of the bucket		bucket

Detailed explaination:

1. It's difficult to predict if the gear ratio 2:1 will provide robot with enough power for climbing to a second zone of a mountain before the test drive. That's why at first wheel base should be realised with gear ratio 1:1. A test model with gear ratio 2:1 should be assembled and tested independently. In case the testing of 2:1 model will be successfull, this gear ratio will be installed onto the main robot.
2. If the bucket would be a size of 5 cubes, it could keep no more 2 balls at once. That's not good enough as when cubes run out our robot becomes uneffective. So, the bucket's capacity should be improved. The possible solution is to improve the length with saving the prior width. For example, bucket with parameters 13×21 cm is enough for containing 5 balls.

Additional comments: The next meeting we will structure ideas into a system.



3.3.4 01.10.2015

Time frame: 17:00-21:30
Preview: The purpose for current meeting was creating structural layout of the robot in CAD Creo Parametric 3.0.

Detailed explaination:

1. We made a structural model of the robot. The whole construction was divided into particular modules. They are:
   1.1. Chassis - carrying base and wheels mounted on it.
   1.2. Bucket - container for debris.
   1.3. Elevator - mechanism for lifting bucket.
   1.4. Gripper - mechanism for collecting debris.
   1.5. MSA - mechanism for scoring autonomus alpinists.

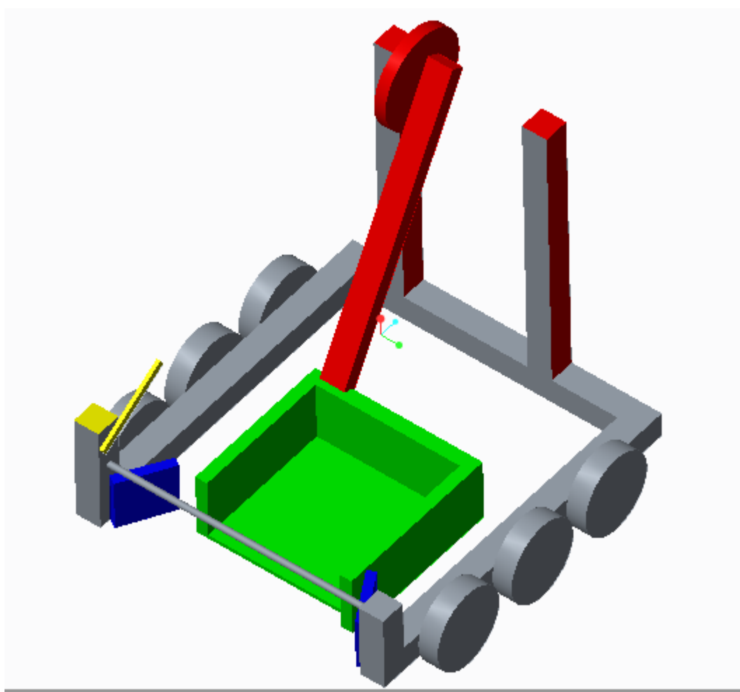
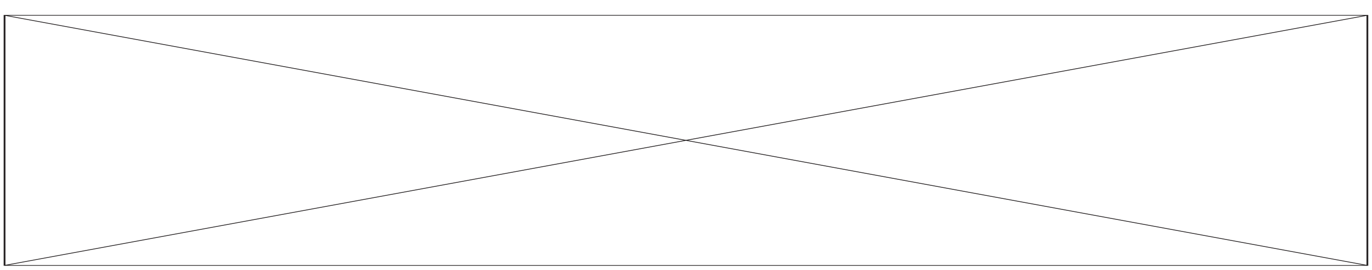


Figure 1: Schematic model of the robot

Additional comments: The task for the next meeting is to summarize our ideas for each module.



3.3.5 03.10.2015

Time frame: 16:00-21:30
Preview: The purpose for current meeting was to divide all construction works into 4 groups (one group for one teammate) to provide elaborating modules in parallel. After that, we wrote technical specification for each group of modules to help collaborators follow the requirements.

Technical specifications for modules:

1. Chassis
   1.1. Carriage consists of two lengthwise beams 41.5cm connected at the back side. All other modules will be mounted to this base.
   1.2. Wheel base consists of 3 pairs of standard wheels. All wheels at one side are linked to each other and move dependently.
   1.3. Wheel base is powered by 6 dc motors (3 at one side).
   1.4. Motors should not interfere with bucket which will be placed in the forward half of the robot.
   1.5. There should be no construction elements except wheels that can touch the surface while climbing the ramp.
2. Elevator
   2.1. Elevator consists of 2 static beams fixed on the base and one pivoting with bucket on it.
   2.2. Turnable beam rotates around the axis on top of the static beams. It's rotation powered by 1 dc motor with gear ratio 1:3.
   2.3. Length of the elevator should be enough for scoring debris into all boxes without climbing to the 3-rd zone.
3. Bucket
   3.1. Bucket should be fixed to the turning beam of elevator.
   3.2. Free space inside the bucket should be 10-14cm at width, 15-17cm in length and 7cm in height. It should be capacious enough for containing 5 cubes of 3 balls.
   3.3. The back side of the bucket can be narrower to prevent collecting more than 5 cubes at once (cubes will settle as $2 + 2 + 1$).
   3.4. Bucket's movement should not interfere with gripper for debris.
   3.5. Entrance hole of the bucket should have the same height and width, as the internal space.
   3.6. Bucket should have a turning flap above the entrance which can prevent balls from scoring on demand. Additionally, the flap will stop debris from falling out of the bucket when it will be overturned.
4. Gripper
   4.1. Gripper consists of 2 rotating blades, mounted to axis at an angle 180° to each other.
   4.2. Gripper is powered by 1 or 2 continious rotating servos or DC motor.
   4.3. Gripper is placed ahead the bucket. Width of blades should match with the entrance of the bucket.
   4.4. Space between axis and field enough for unhindered passage of balls.
   4.5. Gripper should not make any obstacles for bucket's moving.
   4.6. At both sides of the blade's working area placed slopes, which are tapering to the bucket.
5. Scoring autonomous climbers + pushing button
   5.1. The mechanism for scoring autonomus alpinists will be placed at the front right side of robot. It's definite position will be determined after discussion of autonomus strategy.
   5.2. Mechanism consists of F-shaped beam powered by standard servo.
   5.3. At the end of top beam is a bucket for 2 alpinists. The bottom beam pushes the button.

5.4. Module should not interfere with gameplay after the autonomus period ends.

Responsibilities for each module:

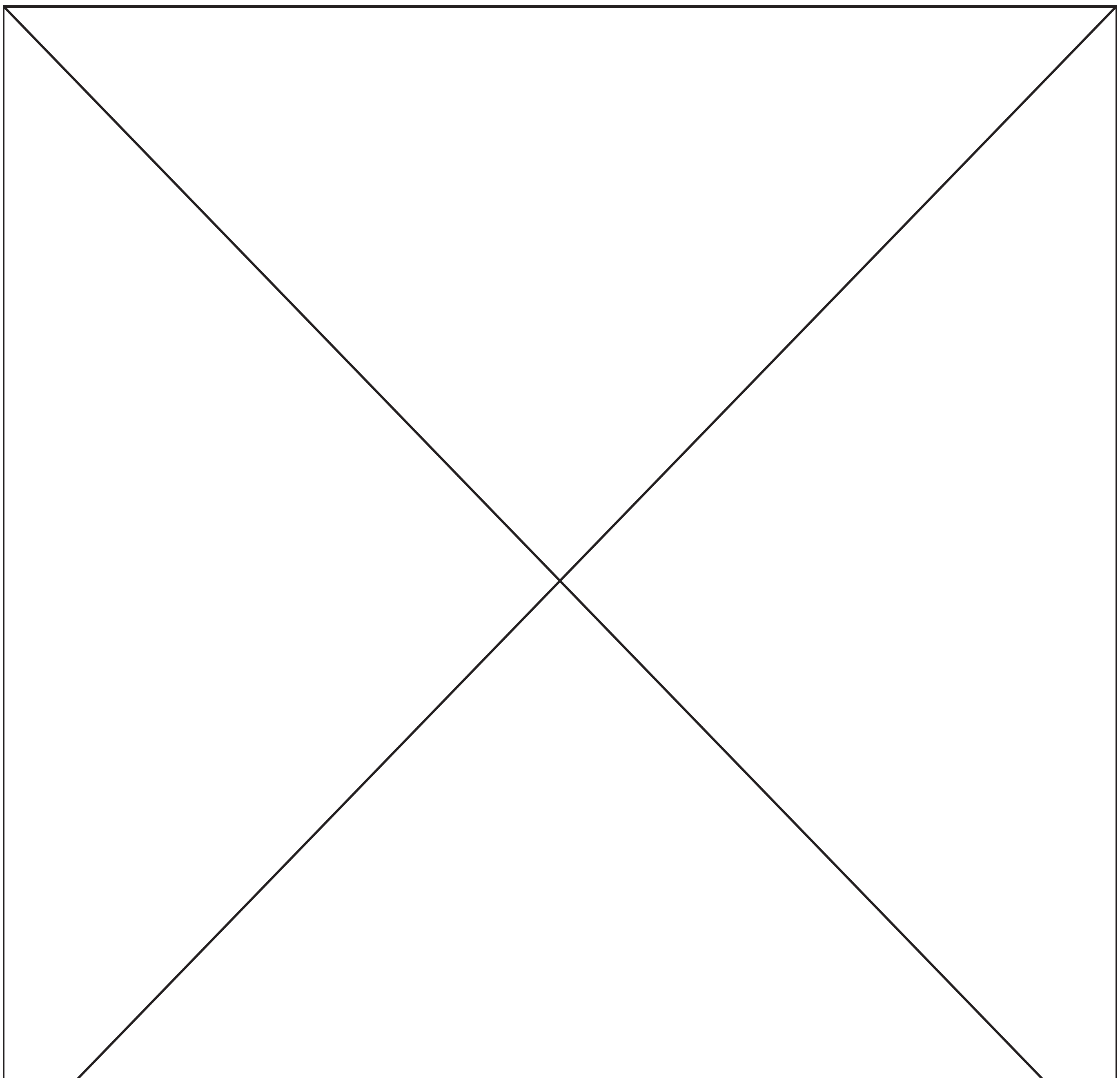
5.1. Carriage and wheel base - Victoria Loseva

5.2. Bucket and elevator - Evgeniy Maksimychev

5.3. Gripper with slopes - Ivan Afanasiev

5.4. Mechanism for scoring alpinists - Timur Babadzhanov

Additional comments: Now our team is ready to proceed to the next objective: designing modules.



3.4 Elaborating robot

Preview: The following section is about elaborating of each module of hte robot. Here it is wrote about all decisions that were looked during designing, what advantages and disadvantages are in the each variant and how was choosed the best.

3.4.1 Wheel base

- Since the robot is only supposed to do one task well, the structure of all the elements had to be optimized for the completion of that one task: collecting debris and placing it in the bins.
- The decision not to pursue completion of other tasks means that we can use some additional motors to boost speed driving speed as well as improve climbing the ramp, bringing their number up from the usual four to six.
- It was decided use six standard wheels. It allow high traction so we can climb to the ramp very well. The central wheel should be located near the COG of the robot. It allow fast and accurate turning.
- The U-contour was chosen as the shape of the wheelbase due to its proven durability and the ease with which other elements may be attached to it.
- The use of a chain to connect the motors and wheels allows for more mobility in changing the position of the wheel, especially since the length of the chain can be changed freely.
- The important moment is that chain should touch a half of circle of the gear. Otherwise it can slip during working. So it was decided to locate gears as in the picture

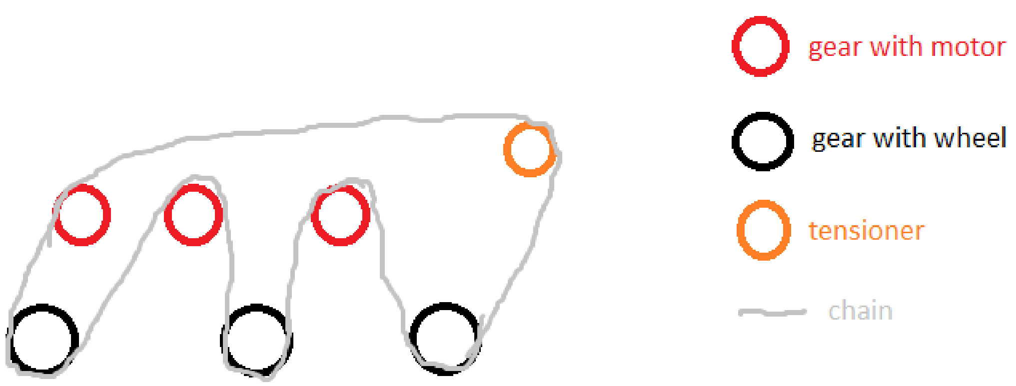


Figure 2: Location of gears for chain

- The first step in creating the wheelbase was making a model in Creo Parametric. Though in subsequent assembly the original design was deviated from, creating this model allowed us to establish a conceptual foundation that we were not to steer away from - usually doing so wastes time and effort.

- To assemble the wheelbase, we needed to shorten a bar and create a chain of the exact length that was needed. In addition, the chain would slack on it's highest segment, and required careful adjustment to ensure that it would not slip while operating.

- During tests and first competition we identified several problems:

  1. Robot can't climb to ramp due to an overextension that prevented the robot from achieving the needed angle. And even if the robot was manually placed on the ramp on the needed position, it couldn't climb on top of the first churro due to low clearance. In order to fix this problem the front wheels were moved slightly forward, so that the distance between the wheel axis and the end of the beam would not exceed a certain value that is easily calculated through the angle of the ramp. After this was done, the robot could easily ride up the mountain. In order to fix the churro problem, we attached treads to the back wheels of the robot. This worked, but doing the same to all six wheels of the robot improved performance even further, and we could easily climb over the first churro in tests. However, when attempting to climb over the second churro, we found that our wheels were placed too close together: the middle wheels pushed into the first churro and prevented the back ones from reaching the second one, and the robot would be unable to advance any further.

  2. Another problem we faced in first competition was the fact that our chain was not protected, and our robot could be disabled very easily just by driving into it and pulling the chain off. We added a metal sheet in front of the most exposed section of chain to protect it.

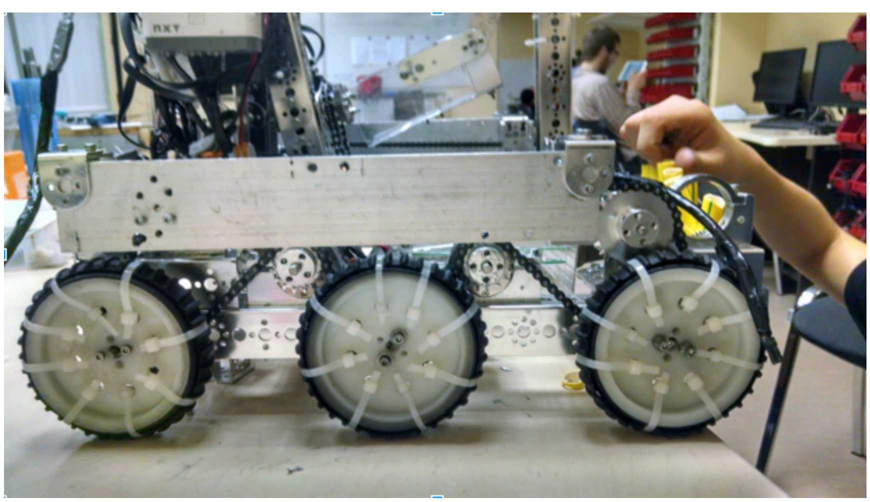
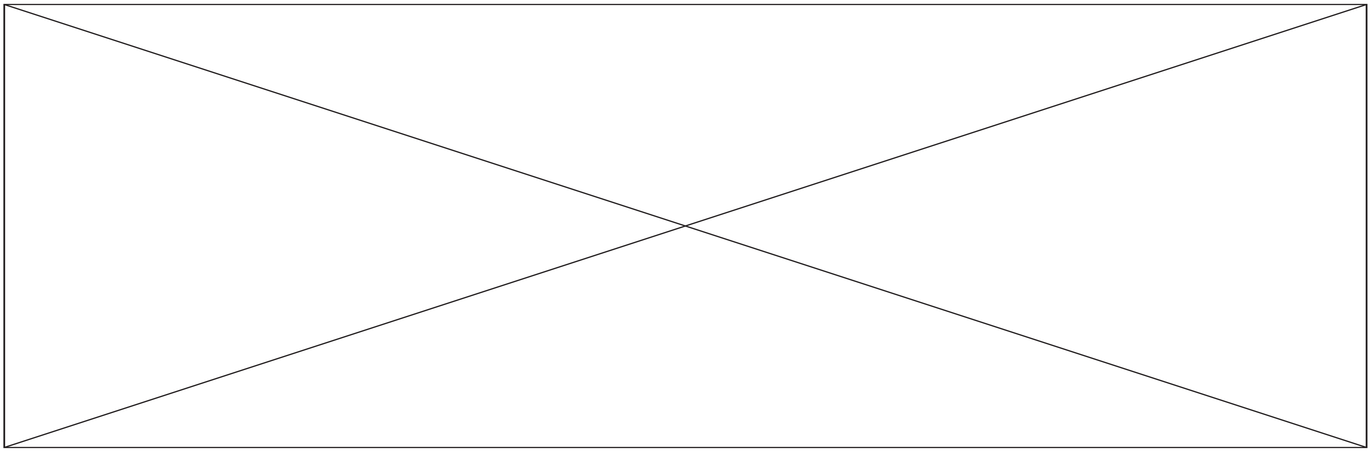


Figure 3: Wheels with caterpillars and protection for chains



3.4.2 Lift

- The lift consists of two beams. One beam is stationar and it is fixed vertically on the back part of the robot. The second beam turns by DC motor that mounted at the top of stationar beam. The length of beams must allow to score debris to the high goal from the middle zone and to middle goal from low zone.

- For estimating optimal length of beams it was made drawing in GeoGebra.

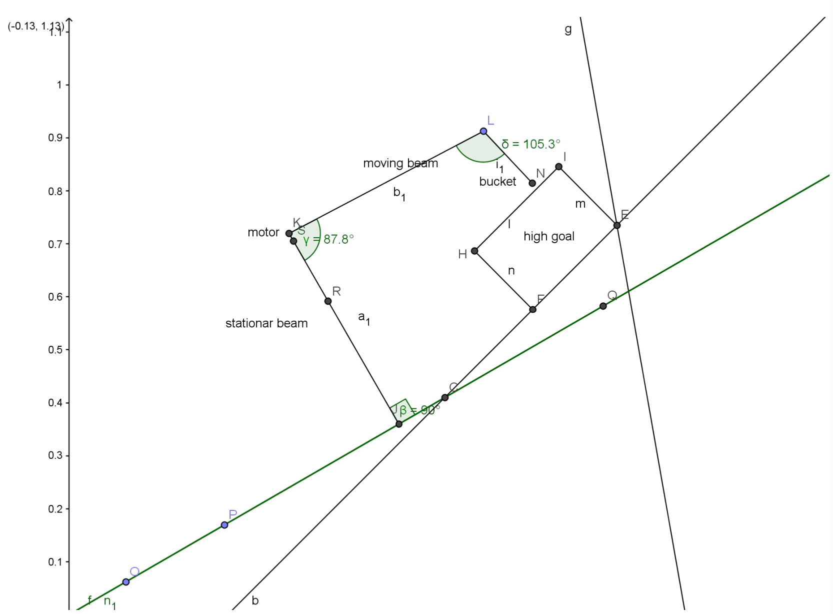
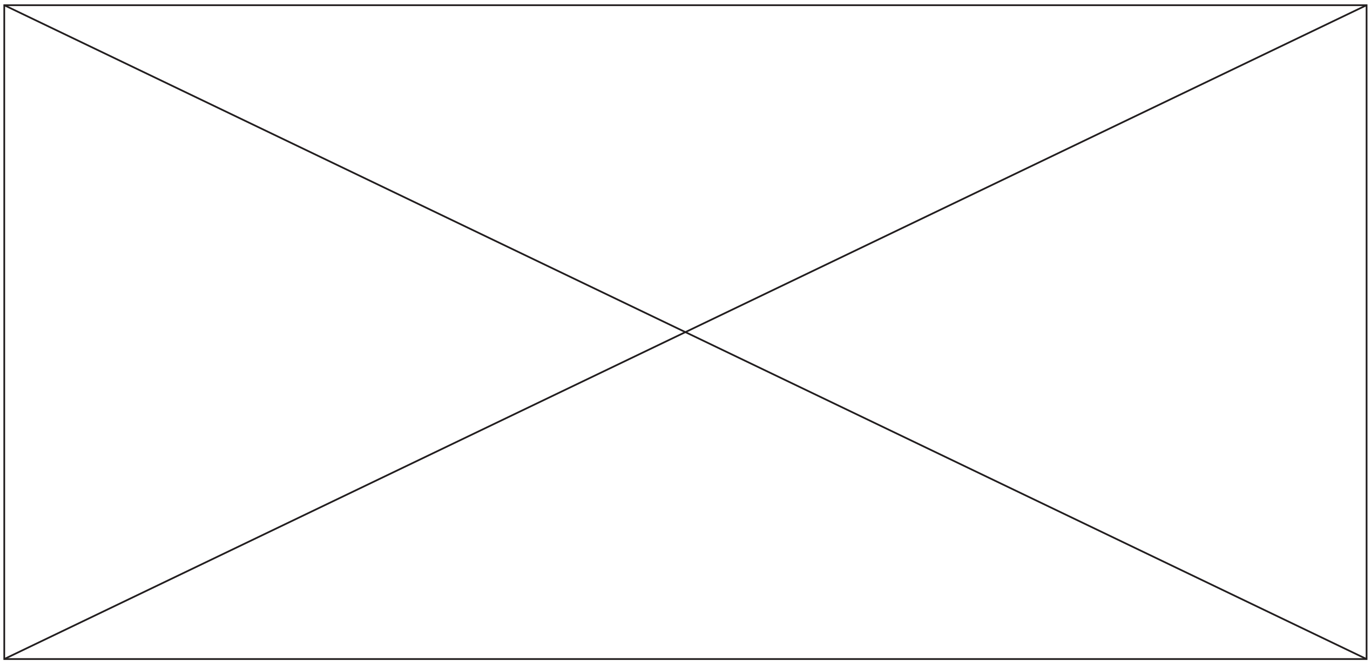


Figure 4: Drawing of the lift

Figure 5: Model of the lift



3.4.3 Bucket

- The bucket's size allow to fit 3 cubes and 2 balls. So we can collect 5 cubes (because size of cube is smaller than size of ball) or 3-4 balls. It is enough for us because we want to concentrate on collecting cubes.

- For estimating optimal size and form it was made drawing in GeoGebra. During designing model of the bucket for all sizes were made dimention tolerances 2cm.

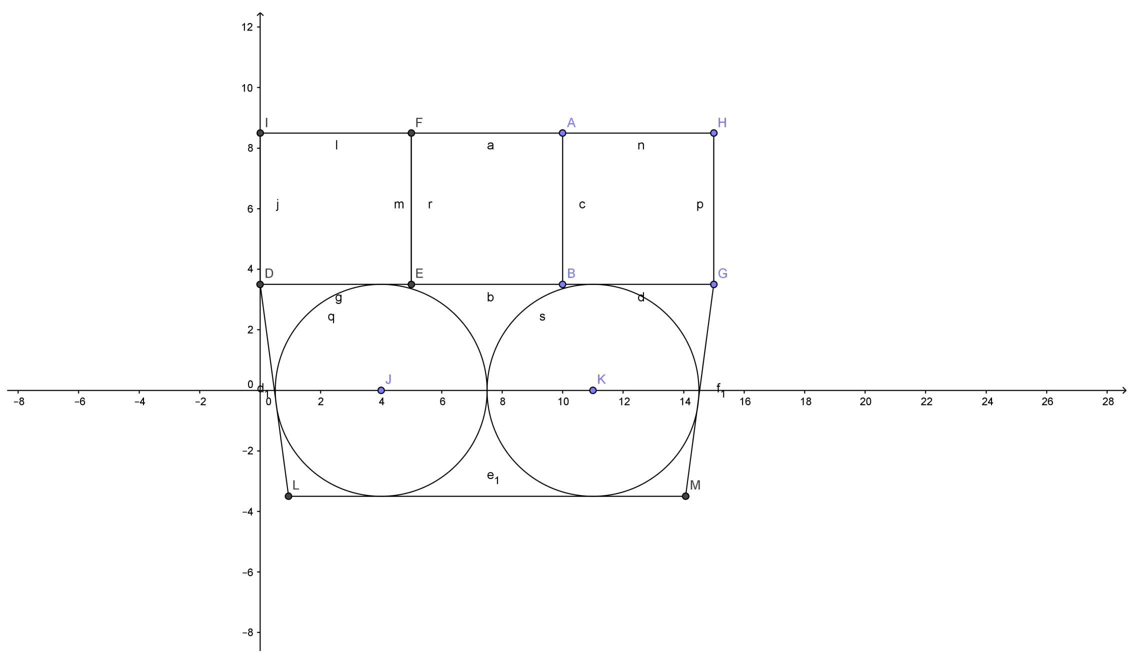


Figure 6: Drawing of the bucket

- But after that it was decided to change size of the bucket. The width entrance hole and width of the scoring box should be the same (The width of the box for debris - 14.5cm. So it was decided to make the bucket's width 13.5 - 14cm). It ensure maximal accuracy of scoring debris. It was decided to make bucket that can fit 5 cubes or 3 balls.

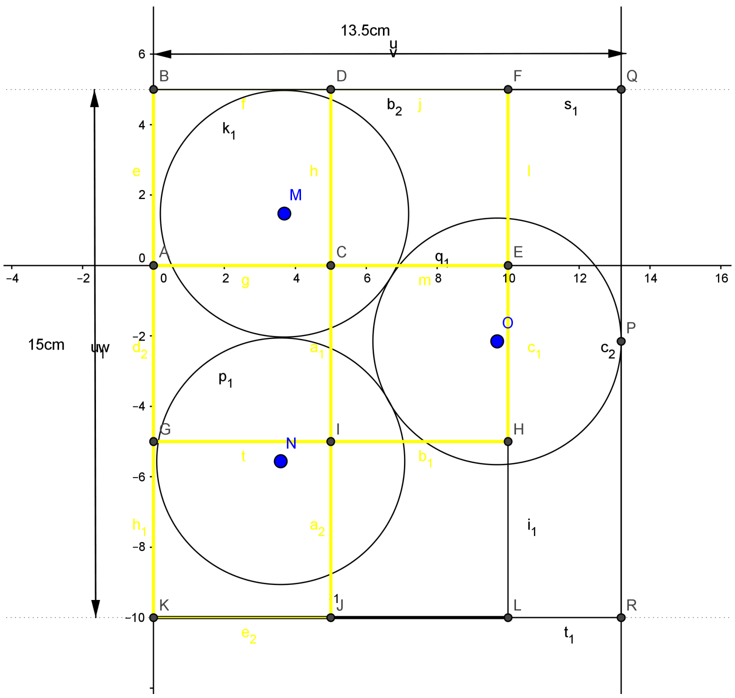


Figure 7: Changed bucket

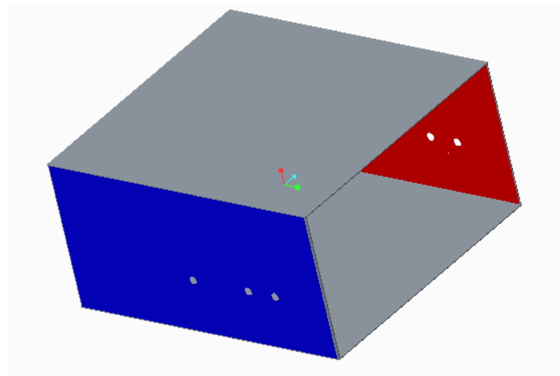


Figure 8: Model of the bucket

- For building bucket it was decided use plastic PET 0.5mm. It is easy to cut it, it light, cheap and clear that allow us to see how much elements are incide the bucket.

- The bucket mounts to beam that turns by the servo which fixed on the lift. It need because else we have to make detail that fix bucket to the elevator on the defined angle. It require high accuracy. So it will be difficult to make this detail. In addition the mount with servo extend operational window of the lift.

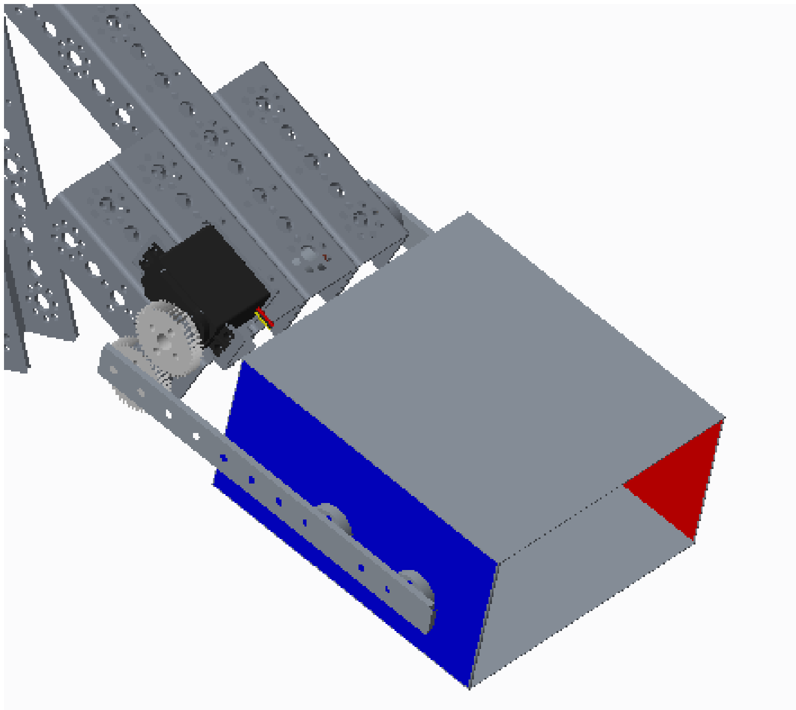


Figure 9: Model of the mount for bucket

- The bucket equped by the cover that turn by the servo and close entrance hole of the bucket. It prevent to falling debris out it during turning of the moving beam of lift. Also it can to prevent balls get into the bucket when we collect only cubes. When it closed not fully (so that distance between bottom edge of cover and floor is about 6cm) the cube can get into the bucket but the ball is not. When we open cover the balls can get to the bucket.
- The cover fix on 14cm beam that turn by the servo. It was decided use so long beam as the most optimal variant when cover move vertically because otherwise it can to prevent rotating gripper for debris. When it turn around the circle with big radius trajectory of cover's moving is close to vertical.

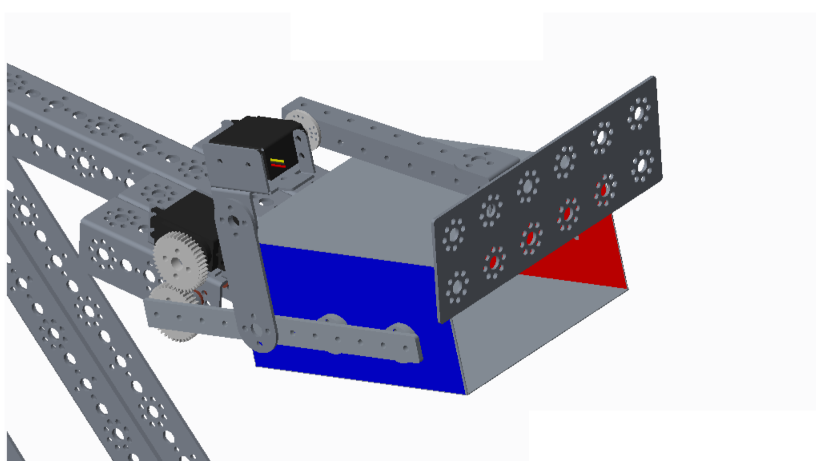


Figure 10: The bucket with cover

- During tests it was found that it will be difficult turn to box by the robot. So it was decided make mechanism that turn it to side.

- The mechanism for turning bucket to side is a beam that turn along the top plane of moving beam of the lift. The servo that turn it is fixed in the middle of moving beam of the lift. It connected with the chain gear (through the transmission in order to prevent failure of servo due to chain tension). The second chain gear is in the bottom of moving beam of the lift and it turn beam with bucket. It was decided make this system because servo take up much space and if it fixed near the bucket it will prevent it's turning.

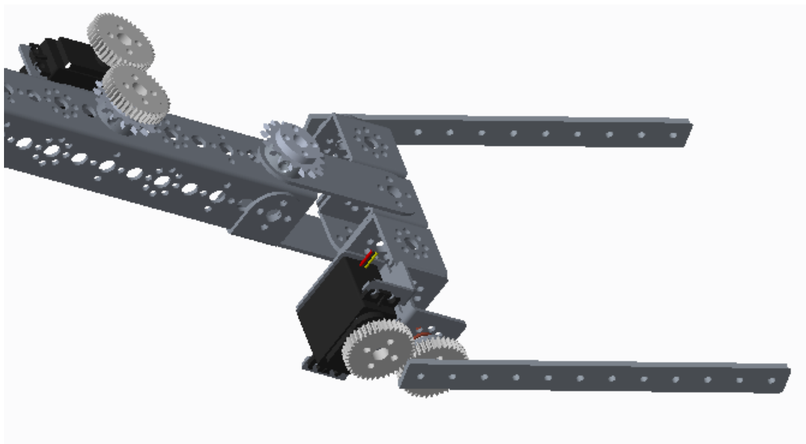
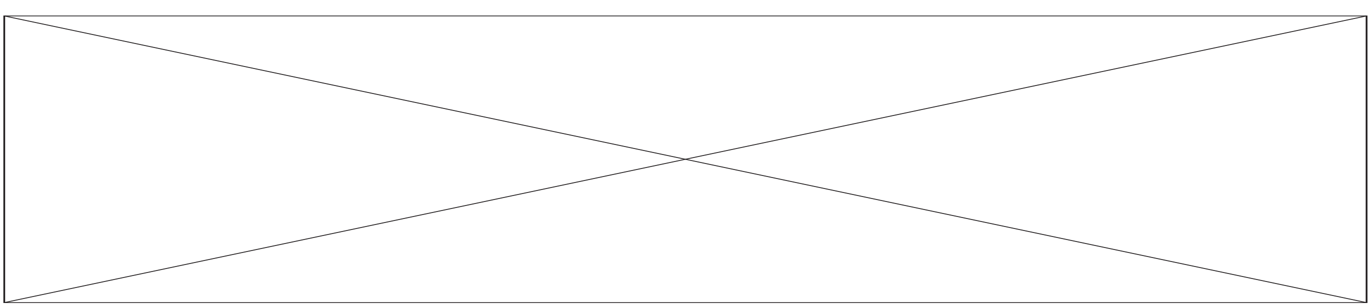


Figure 11: Mechanism for turning bucket to side

- Also they were calculated moments of force that acts to servos. From this calculations they were choosed servo for turning bucket and cover. During the calculation were taken into account mass of construction elements and safety coefficient 1.5 For turning bucket (up and down and to side) it was decided use servo MG995 (torque 11kg*cm) for cover - HS-485HB(torque 5.9 kg*cm).

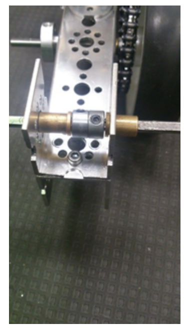
	bucket	debris	cover servo	beams for mount bucket	cover	beams for mount cover	bucket up-down servo
weight, g	50	250	43	50	57	33	70
lever for bucket servo,cm	9,5	9,5	5,60	9,5	18	11	
lever for cover servo,cm					14	7	
levr foe turn bucket servo	14,3	14,3	10,4	14,3	22,8	15,8	4,8
	torque, kg*cm			safety coefficient			
bucket up-down servo	7,4322			1,5			
cover servo	1,5435						
bucket side servo	11,4138						

Figure 12: The table of moments



3.4.4 Gripper for debris

For rotating brush it was decided use DC motor. It allow the fastest collecting debris.
The first part of module is the mount to the base and axis. The brush is fixed on it.

		
	Mount for axis	

Also it was made protection for wiring of the motor. It is the construction of Tetrix plates that fixed to the base rigidly.
The next element of the module is the brush. The brush should be tough enough so that it doesn't bend during collecting debris. But it should be elastic in order to when robot hit the wall of field the brush bend but not broke.
At first it was made brush made of piece of plastic bottle. During the test it collect debris good enough but it started crack.

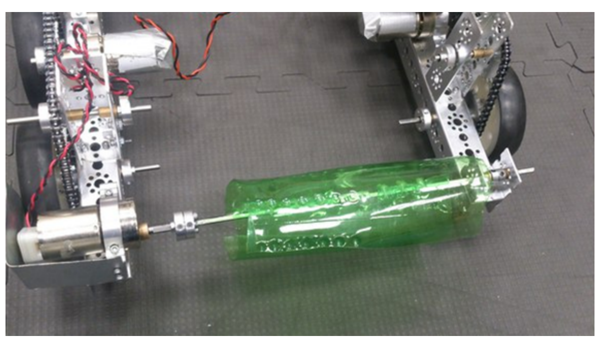
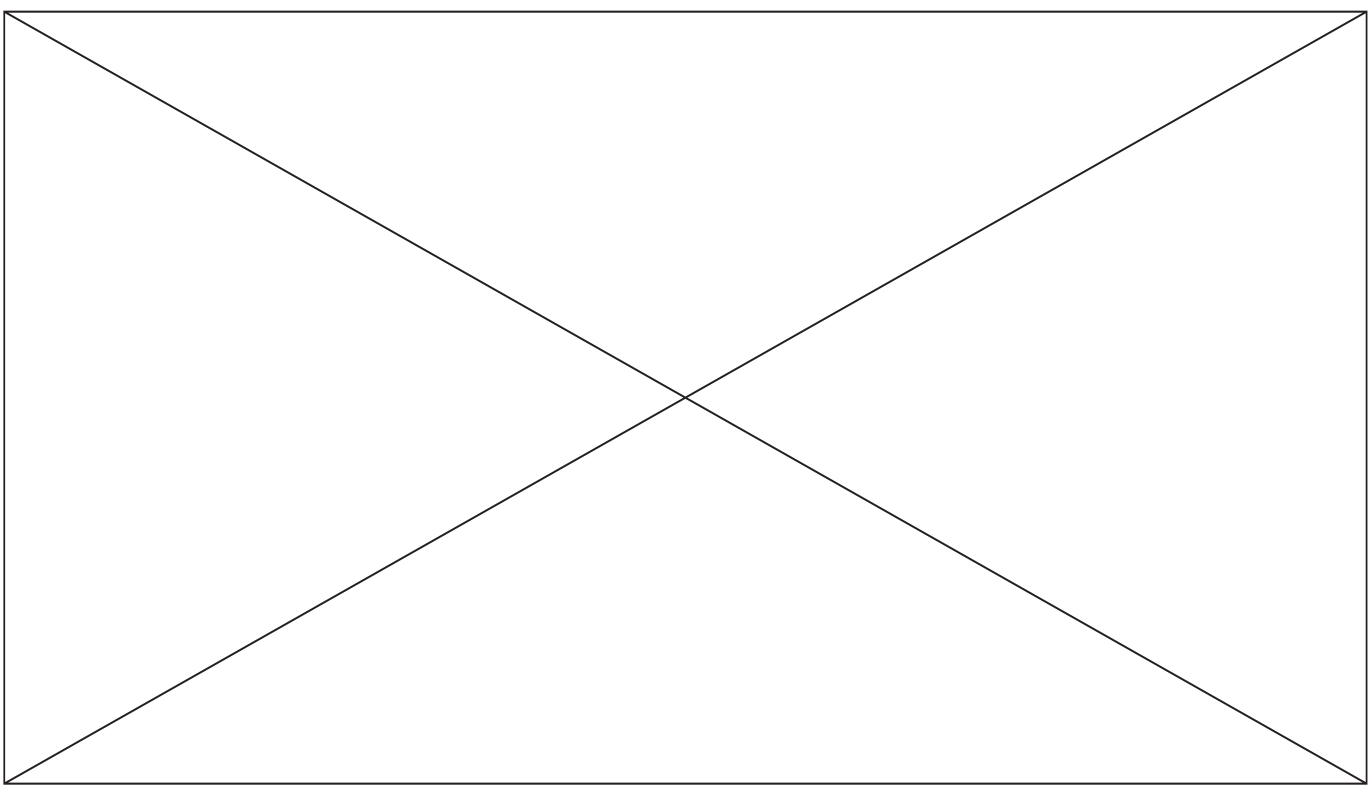


Figure 13: Brush madde of plastic bottle

So it was decided to use pieces of rubber hose because it is elastic but more durable than plastic. Pieces of hose were fixed on the aluminium tube from Tetrix set with help of screws. The tube was instaled on the shaft of motor instead of axis. This construction worked good enough. It collected debris without problems.

Figure 14: Gripper with hose

Later it was decided to increace speed of rotation gripper and install transmission with gear ratio 1:2. It need for pushing away scoring elements durin autonomous period.



3.4.5 Mechanism for scoring autonomous climbers and pushing button

Plan of creating module:

1. Creating 3D model in Creo parametric.
2. Calculation of moments, distances and angels.
3. Testing and debugging of the mechanism

The module turns F-shaped beam using servo. On the top of beam is a bucket with climbers. After beam turns, bucket turns over. Climbers go to the box. At the end of other part of a beam is a light sensor. He detects color of a button and presses it. Robot performs it at autonomous period.

Ideas that were looked:

1. The first idea was the following: we decided to use two beams. Two beams turns, the light sensor on the end of each beam detects the correct button. Beam, which detects the correct button wrests in place. The other beam turns up. The robot goes forward and presses the correct button. But this idea isn't good because we using two servos and this is very difficult and the module take up much up space.
2. Another idea was the following: we decided to use one beam. The beam turns and the light sensor on the end of the beam detects the color of the right button. If this color is correct, the robot turns right and then goes forward. Else the robot turns left and then goes forward. This algoritm is slower, but it's lighter and the model takes not as much space. We decided to use twice algoritm.

Calculation of moments We calculated the moments to compare it with the maximum moment of the servo. If the maximum moment of the servo is higher than the moment of module, the module will work. The maximum moment of the servo(HS-485HB) is 28 kg*mm. The moment of gravity forces using the following formulae:

$m_{\text{constr}} \cdot l_{\text{constr}} + m_{\text{climbers}} \cdot l_{\text{climbers}}$. M_{constr} is the total mass of the module without climbers. L_{constr} is the distance between the rotation axis and the COG of module without climber. M_{climbers} is the total mass of the two climbers. L_{climbers} is the distance between the rotation axis and the COG of climbers. All values we find in Creo Parametric.

M_{constr} is about 100 g or 0.1 kg. L_{constr} is about 93 mm. The moment of construction is about 9.3 kg*mm. Mass of a climber is 22.7 g. Mass of two climbers is 0.0454 kg. The COG of climbers and geometrical center ar ine the same place, because the climbers are uniform. It is about 204 mm. The moment of gravity forces if the all module is 18.9 kg*mm. Safety factor is 1.5. With this factor moment of module is 28 kg*mm. The moment of module is not bigger than the maximum moment of the servo. The module will work.

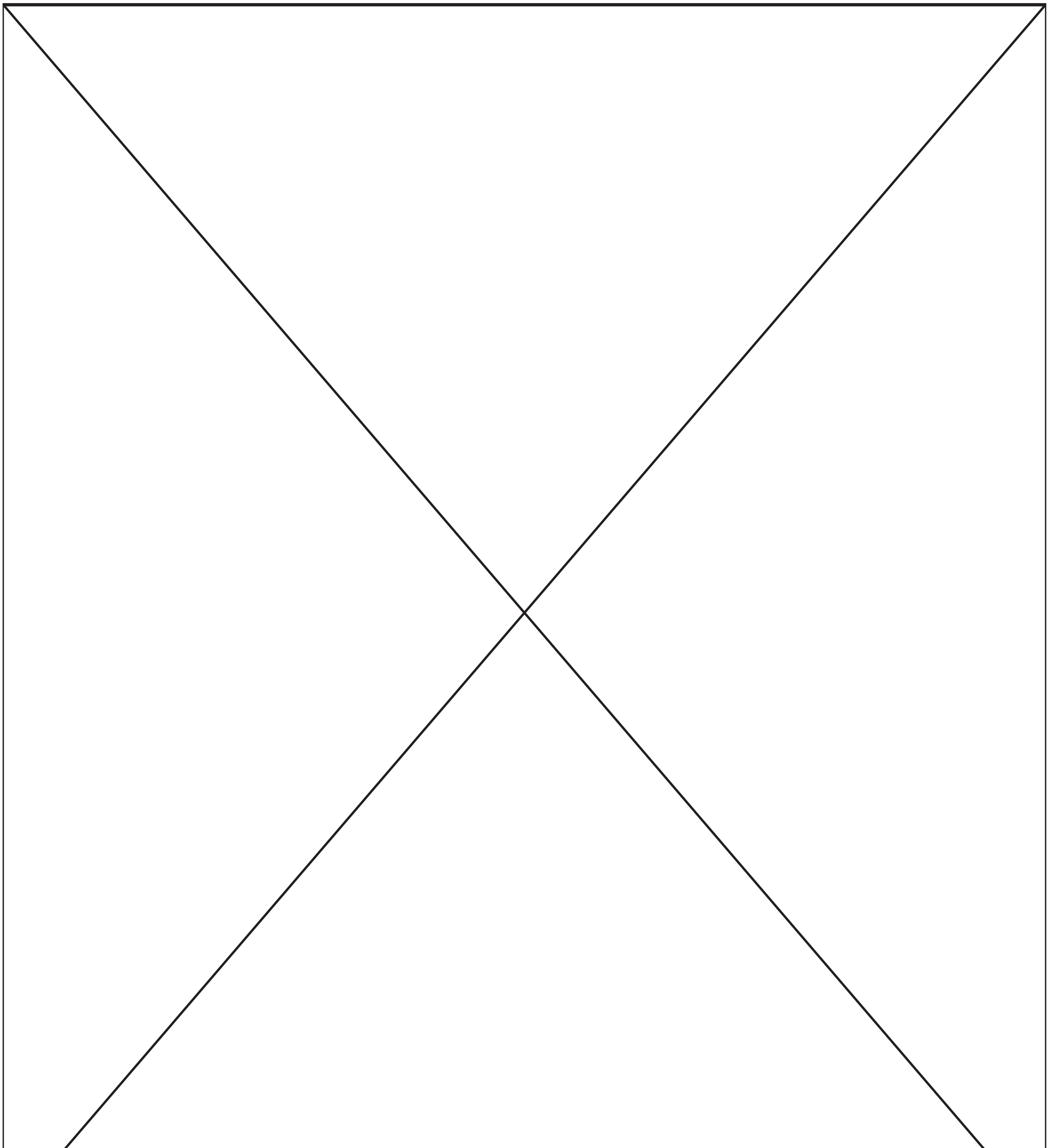
	Distance to COG, mm	Mass, kg	Safety factor	Moment, kg*mm
Without climbers	96	0,1	1,5	14,4
Climbers	204	0,0454	1,5	13,8924
With climbers				28,2924

Figure 15: The table of moments

Work of module

- A dimension of the bucket is 6x5.5x12 mm. A dimenension of the main beam is 20x0.5x1.5 mm.

- The robot must stay near the button on the distance 16.9 cm. Also the main beam must be in the middle of the beacon. Than the robot turns beam on 48 degrees and the climbers go down. Than the robot must go forward on the distance 5 cm. After that the robot turns beam on 42 degrees. Than the robot detects correct button and turns in his side on 9 degrees. At the end the robot goes forward and presses correct button.



3.5 Team meetings and events

3.5.1 16.11.2015

- Today it was assembled wheel base of the robot. The chain wasn't connected.

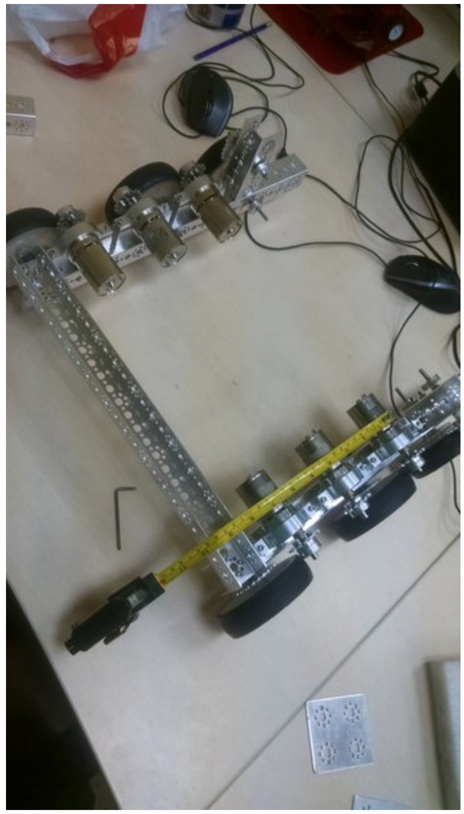


Figure 16: Wheel base without chain

- Also it was made the gripper with plastic bottle.

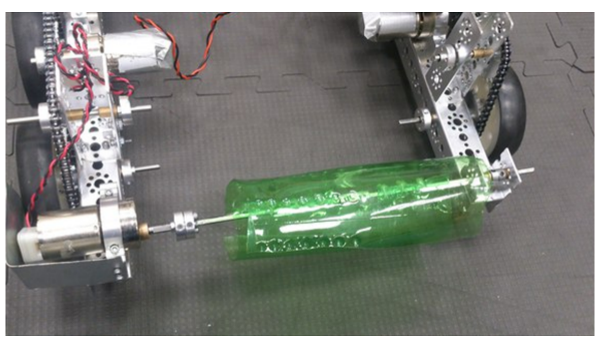


Figure 17: Gripper with bottle

3.5.2 19.11.2015

- Today the chains were connected to gears on the wheel base. It was wrote the programme for tele op and wheel base was tested on the field. Robot can move and turn fast and accurate

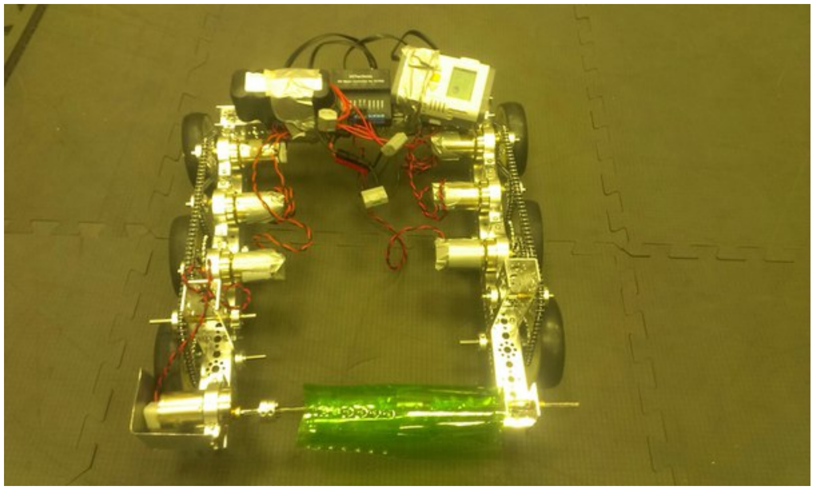


Figure 18: Wheel base with chain

- Also it was assembled the lift. But it wasn't installed on the robot.

3.5.3 21.11.2015

- The trainings with wheel base were continued. Also the mount for bucket was installed on the lift.

3.5.4 23.11.2015

- It was made and fixed on the lift bucket for debris. In addition the lift was installed to wheel base.

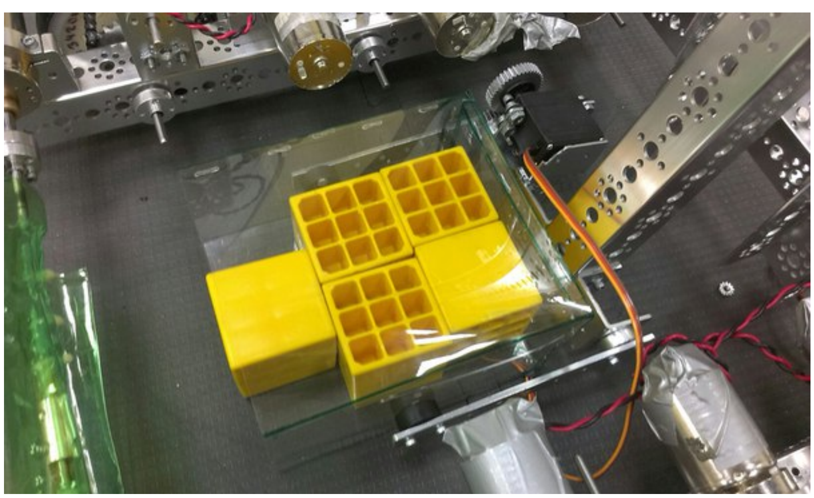


Figure 19: The bucket for debris

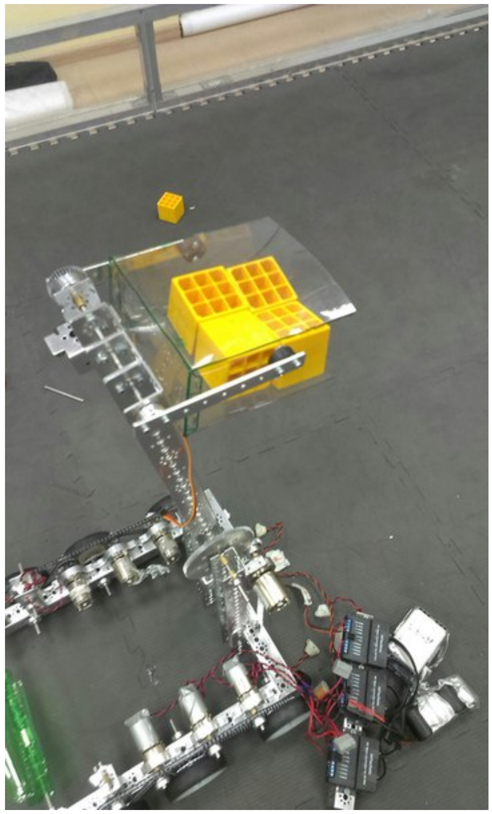


Figure 20: The bucket on the rised position

3.5.5 24.11.2015

- It was found that gears on servo that turn bucket slip under the loads. So it was made the plate that doesn't allow to gears go away from each other.
- It was installed the cover for bucket.

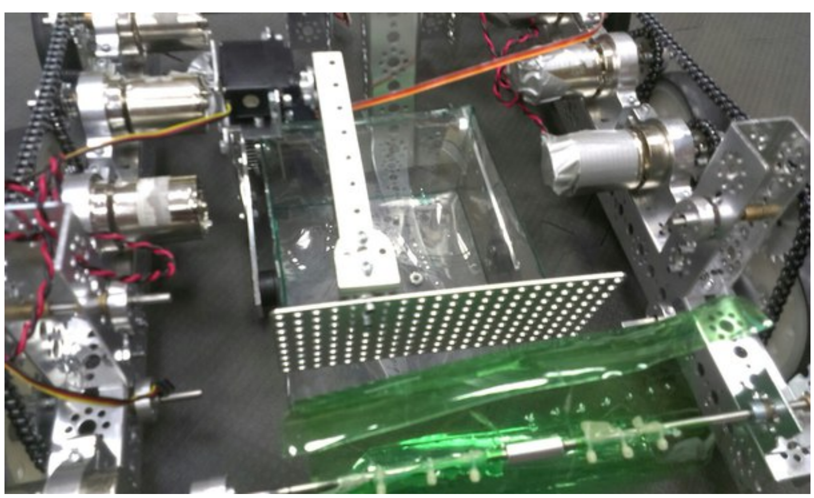


Figure 21: Cover closed

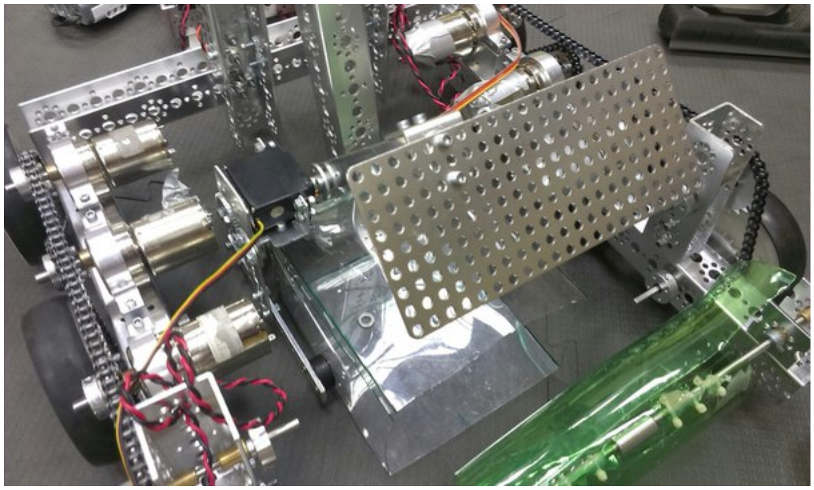


Figure 22: Cover opened

- Also they were cut the slopes for gripper.

3.5.6 25.11.2015

- The slopes were installed on the robot. '
- Also today we bought the hose for gripper.
- Motor and servo controllers and NXT brick were installed on the robot.

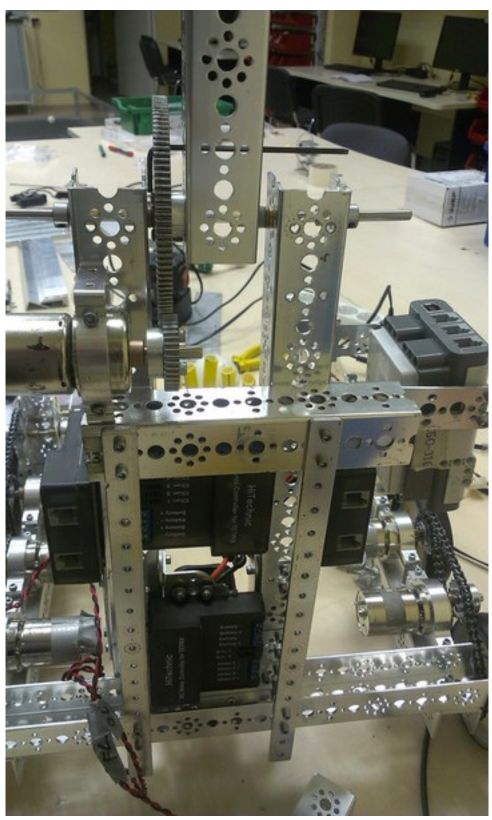


Figure 23: Controllers

3.5.7 26.11.2015

- Today were hold wires of power for controllers.

3.5.8 27.11.2015

- The wiring of motors was hold.

3.5.9 28.11.2015

- It was found that the chain slip on back motors. So they were mounted so that chains touch larger sector of the gears that rotate by this motors.

3.5.10 30.11.2015

- The wires for servo were hold. Servos were set up. The programme for tele op was finished.
- They were connected encoder of the motor that turn lift and encoder of the right side of wheel base. The left encoder of the wheel base wasn't connected because we had not enough wires for encoder. But if we need move on straight line or turn by both wheels pairs one encoder is enough.
- The brush of gripper was remade.
- Also we tested climbing to the ramp. It was found that robot can't do it because the front wheel is too long from edge of robot. So it was decided to score only to low box on the closest competition (5 - 6 of December). That is because we haven't enough time to remake something so it is better to train score to low box and write good autonomous period (score climbers and push button). In addition we tested how robot can score to middle box if it climb to low zone. It was found that it is very hard if we turn by the robot. So we need mechanism that turn bucket to the side. It was decided to make it after the competition. In addition it was found that it is difficult to ride to middle zone. So we need make mechanism that extend moving beam so that it can reach high box from low zone. But it was decided make it after competition too.
- It was found that we can score bottom zip line climber if we push it by the bucket for debris.

3.5.11 01.12.2015

- Today operators trained on the robot control. In this process it was found that screws that fix gears on motors get out. So they were fixed with help of sealant.
- During trainings we reached the next result: full low box in 2 minutes.

3.5.12 02.12.2015

- Today we were writing programme for autonomous period. It was wrote riding to the button and framework for pushing button. Now robot navigates by encoders. Also it was installed F-shaped beam.

Figure 24: F-shaped beam

3.5.13 "Robofest-South" (5-6 of December)

The team members who were in this competition:

1. Evgeniy Maksimychev: programmer, operator 2
2. Timur Babadzhanov: public relation, operator 1

5 of December Today there were trainings and judging.

- This day we made autonomous period for this actions: ride to shelter, score climbers and stay at repair zone. It give us 45 points (2x(10 + 10) - climbers for autonomous and teleop 5 - robot in repair zone). During this process it was found that robot can't move on a straight line accurate by one encoder due to a different tension of chain in different sides of the robot. So it was decided to remove the wire for encoder from the motor that turn lift and connect the second encoder of the wheel base. Then it was wrote proportional regulator that give more power to motor that turned on a smaller angle. It allowed to solve this problem. Alos it was found that cubes and balls can prevent to working of the robot during autonomous period. So it rotate by the gripper and repels debris. But if the gripper rotate faster it will work better. So we need to install transmission for increasing speed.
- Also today operators trained on the robot control. We reached the next result: full low box and scored buttom climber in 2 minutes.
- In addition we communicated with other teams. There are 13 teams in this competition (including our team). It was found that only one team can score to low box. The rest teams are able to score debris to floor goal and 2-3 teams can score buttom climbers. Also about five teams can climb to low zone of mountain and one - to middle.

6 of December Today there were qualifying and final matches.
Qulifying mathes (3 mathes):

1. First match. In automous period we got 5 points (didn't score climbers, ally hadn't automous). In teleop period we didn't score debris because we hadn't charged battery so our lift didn't work. Our ally scored about 7 elements to floor goal. We lost this match.
2. Second match. 5 points for autonomous (the same situation as in first match). In teleop we scored 10 elements to low box and pushed buttom climber. Our ally scored about 10 - 12 elements to floor goal and partically parked in low zone.
3. Third match. We scored climbers in autonomous and stayed in zone. In teleop we scored 13 elements to low goal and pushed buttom climber. Also we pushed our ally to the mountain. So it was able to park in low zone. In addition our ally scored 10 elements to floor goal.

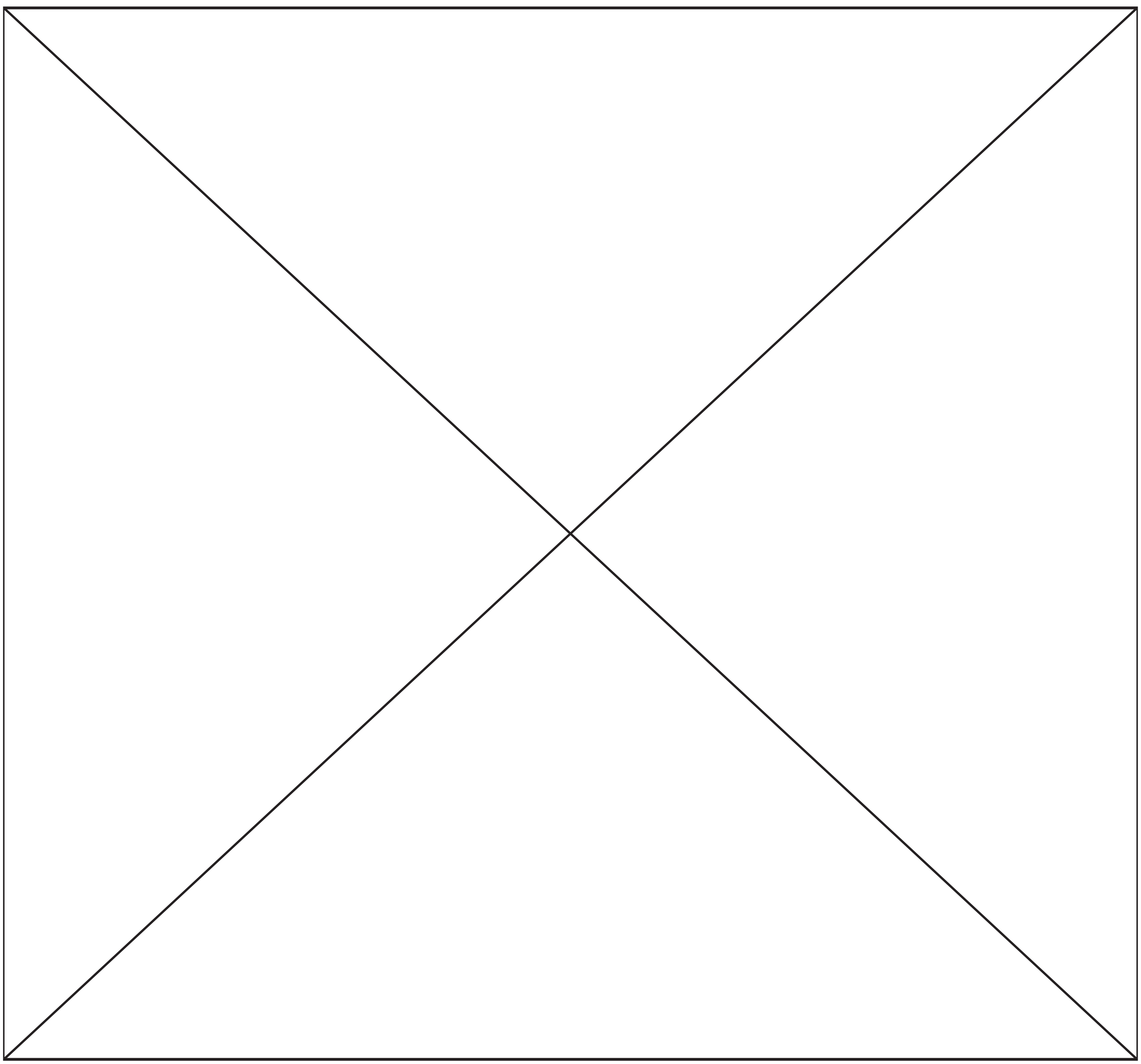
By the results of qualifying matches we became 4th. So we could choose ally for final matches. But we decided to play with team PML 30 - Y (that became 2th) because they could push buttom climber in teleop and score debris to floor goal very fast. So we can concentrate on scoring to low box
Final matches:

1. Semi final 1. We didn't score climbers in autonomous (got points only for repair zone). In teleop we scored 9 elements to low box. Our ally scored 12 elements to floor goal, pushed climber and partically parked in low zone. We scored so little debris to low box because our opponent dropped our box from the mountain and we didn't understand what should we do immediately.

2. Semi final 2. We didn't score climbers in autonomous (got points only for repair zone). In teleop we scored 13 elements to low box. Our ally scored 15 elements to floor goal and pushed climber.
3. Final 1. We didn't score climbers in autonomous (got points only for repair zone). In teleop we scored 12 elements to low box. Our ally scored 14 elements to floor goal and pushed climber.
4. Final 2. We scored climbers in autonomous and stayed in zone. In teleop we scored 11 elements to low box. Our ally scored 12 elements to floor goal and pushed climber.

Summary:

1. We scored to low box stable.
2. Programme of autonomous period worked badly (2 times from 7 matches it worked).
3. In general mechanisms worked stable. But one motor that turn lift had broke (failure of reducer). Also during one match the chain fell due to collision with other robot.



3.5.14 8.12.15

Today we discussed results of competition and improvements that we should make in the robot
Problems and solutions for each module:

1. Wheel base:

Problem	Solution
Can't climb to mountain	To move front wheels forward
Chain isn't protected	Install protection of plexiglass or metal

2. Lift and bucket:

Problem	Solution
Bucket don't turn to side	To make mechanism that turn bucket to side
Lift can't reach high box from low zone	To make mechanism that extend moving beam of the lift
Reducer of the motor that move lift broke	To fix axis of the motor more rigidly

3. Gripper for debris

Problem	Solution
Rotates too slow	To install transmission with gear ratio 1:2

4. Mechanism for scoring climbers

Problem	Solution
Climbers sometimes get stuck in bucket	To extend bucket or make it narrower and put climbers on each other

5. Also we need to improve programme of aotonomous period. It was decided to turn with help of gyro or compass sensor.

6. In addition during one match NXT brick fell off. So we need fix it more reliable.

3.5.15 9.12.15

- It was estimated place for front wheels.
- It was started designing of mechanism that turn bucket to side.

3.5.16 10.12.15

- It was finished designing mechanism for turning bucket for debris to side.
- Bucket on F-shaped beam was extended. So climbers don't fet stuck in it.

3.5.17 12.12.15

- Front wheels were moved forward.
- Mechanism for turning bucket to side was assembled but servo that move it wasn't installed.

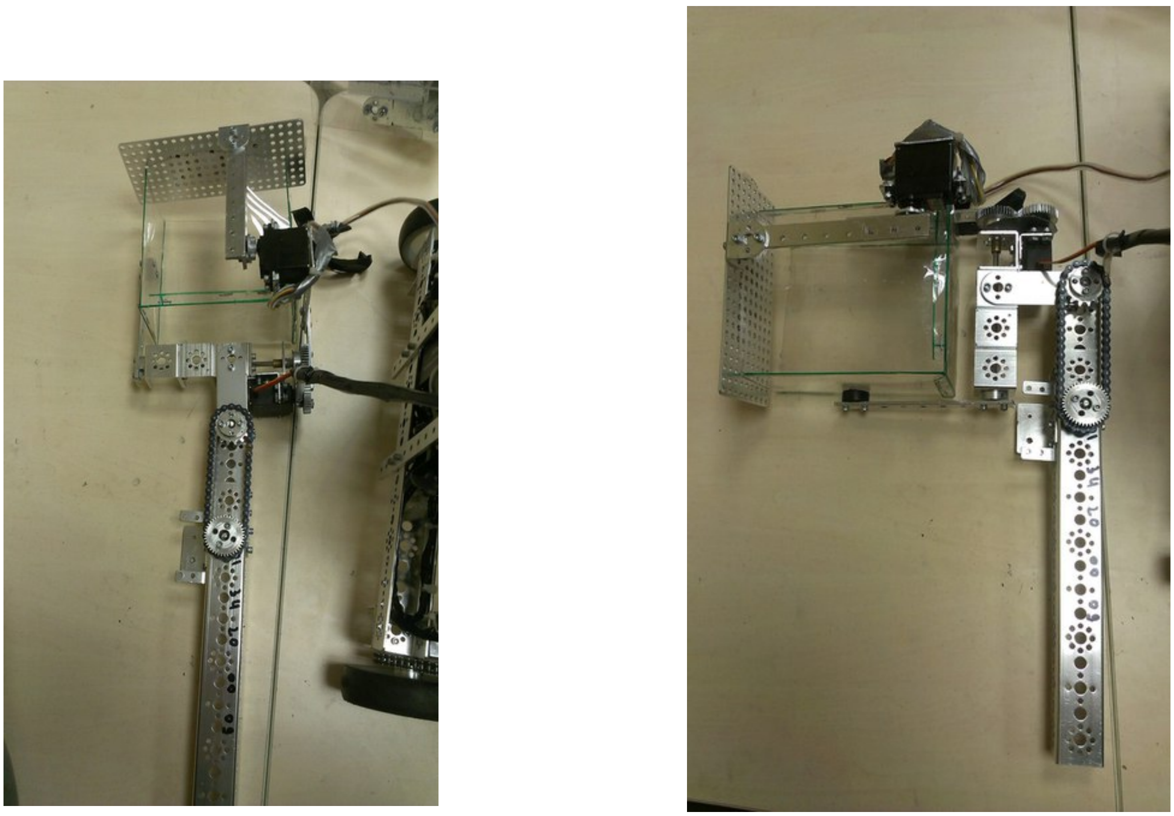


Figure 25: Mechanism for turning bucket to side

- It was started assembling new gripper for debris.

3.5.18 14.12.15

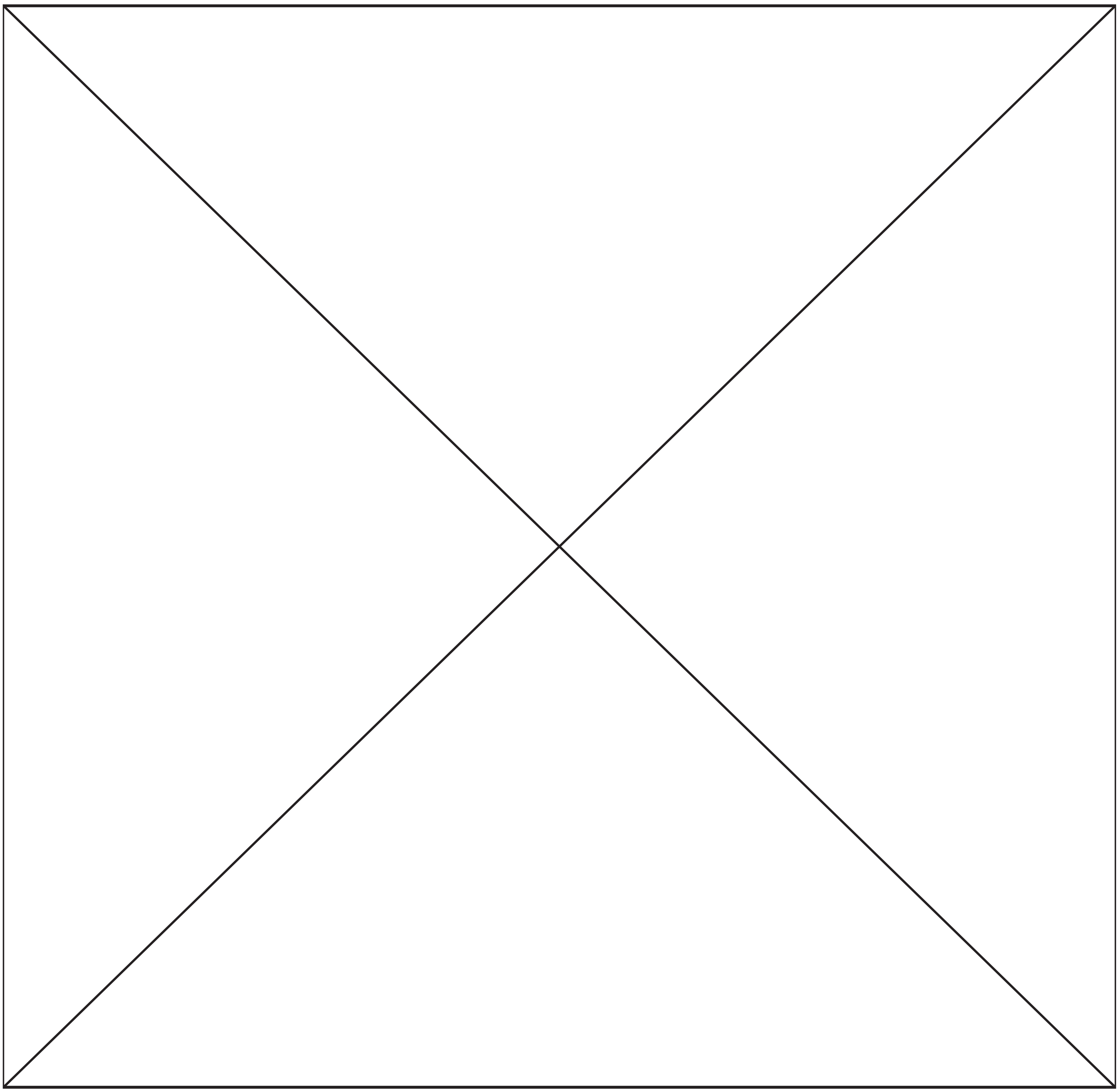
- Climbing to mountain was tested. Robot can reach low zone. It was decided install Lego caterpillars for better traction. After that robot was able to climb to low zone and overcome bottom obstacle by the back wheels. Also it was found that if we move central wheels forward so that back wheels touch second obstacle before central wheels toch first obstacle (now central wheels touch bottom obstacle first) robot most likely will be able to climb to middle zone.
- It was started installing new gripper for debris.

3.5.19 15.12.15

- It was installed servo that turn bucket to side.
- The axis of the motor that move lift was fixed rigidly.
- It was installed protection for chains.

3.5.20 16.12.15

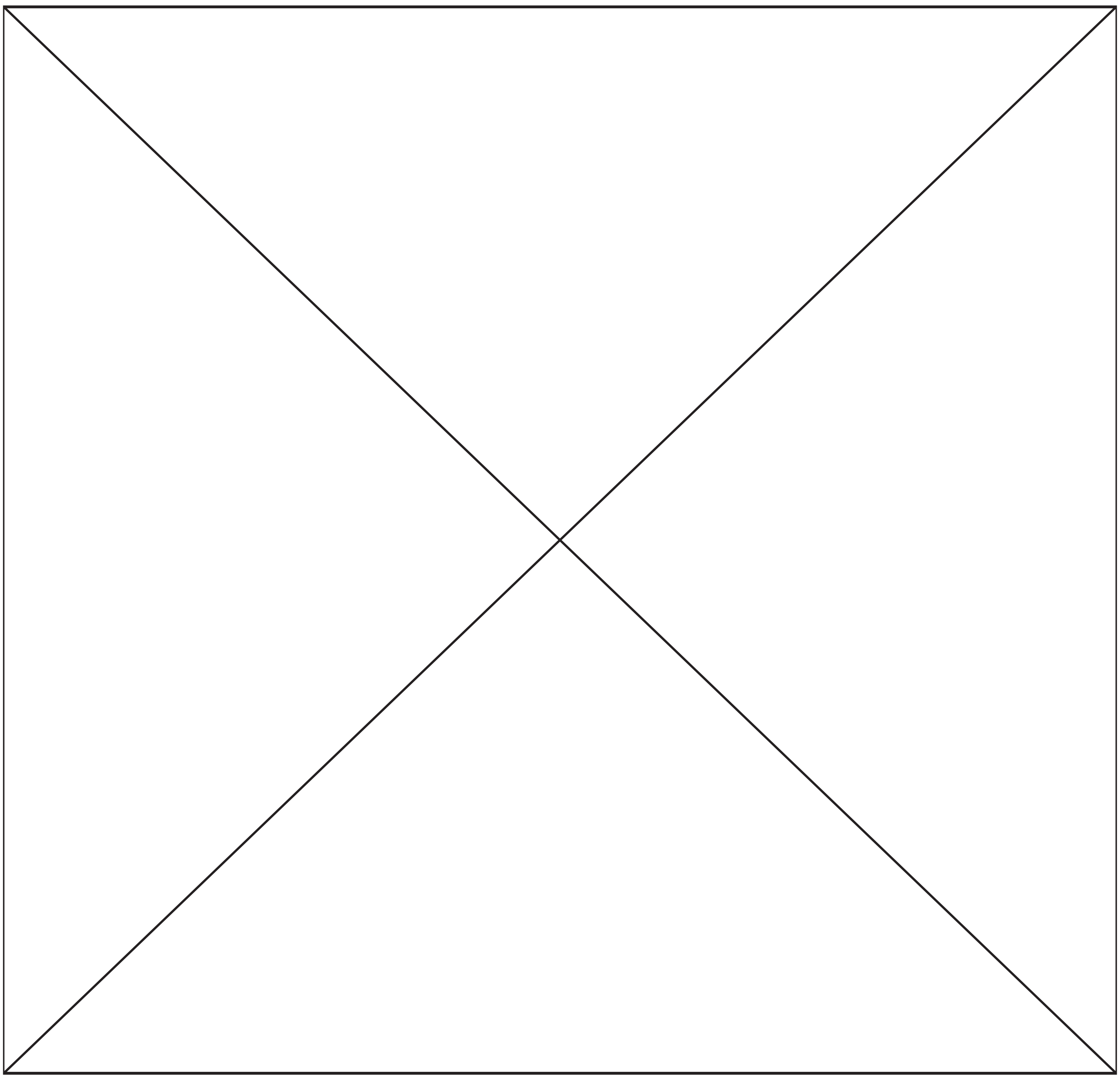
- It was held wiring for servos that turn bucket.
- The gripper for debris was installed.



4 Appendix

4.1 Supplementary materials which were used in the robot's construction

1. List of PET 1 m 80 cm. 1 piece.
2. Tape.
3. List of plexiglass 3m x 2m (cut). 1 piece.
4. List of galvanized steel 0.5mm (cut).
5. Rubber hose.
6. Servo MG995.



5 Thanks and prospects

We enjoyed working on a custom and non-standard project, which, besides its technical aspect, included working with new people who shared our values of friendship and mutual understanding.

Our team is planning to continue doing robotics, setting new goals for ourselves in order to improve. This is our first year taking part in FTC and we will participate next year as well. If we don't realize ourselves this year, we'll look at all our mistakes, correct them, and preform a lot better next year.

In any case, we are ready to learn new things, improve ourselves and expand our skills.

None of us know for sure what we want to do in the future, but we are certain that our experience will be very valuable to us.

Our thanks go to the company FIRST for organizing this competition, which we are very happy to be participating in. We appreciate this wonderful opportunity to test ourselves and learn something new and wish them success and growth in their future endeavors.

Also we thank our sponsors: company PTC and it's Russian representative "Irisoft" and charitable foundation "Finist" for their support. Also we thank Physics-Mathematics Lyceum 30 and it's director Alexey Tretyakov for providing comfortable conditions for preparation to competition.

Team PML 30 X