Engineering and Design Journal

FTC Team 4278 de.evolution

Abstract

FTC Team 4278 proposes the creation of a robot to address all aspects of the FTC 2013-14 competition, “Block Party.” The proposed design has the capacity to address, in the teleoperated period: (1) retrieval of blocks; (2) placement of blocks into the block crates; (3) raising the FTC flag; (4) hanging against the field bar. In addition, during the autonomous period, the robot will address the following elements: (1) placement of blocks in the correct bin, as indicated by an IR beacon; (2) maneuvering to the ramp.

In order to achieve these goals, it was determined that the robot should: (1) be very difficult to push; (2) be fast and reliable in movement; (3) have a low center of gravity; (4) have as few unique components as possible; (5) be as compact as possible; (6) pick up blocks with at most one motion; (7) place blocks in crates with at most one motion; (8) hang with at most either two motions on an existing component, or one motion on a new component; (9) be able to raise the flag with one component; (10) be electrically stable, generating as little static as possible.

Goals set for autonomous include: (1) being able to score in the crate denoted by the IR beacon; (2) being able to travel to the nearest ramp; (3) being able to address and recover from any problems which may arise on the field, including, but not limited to, obstructions caused by other robots; (4) potentially being able to score both autonomous blocks. For (3), the intent is to travel onto the ramp regardless of potential obstruction by other robots. Decision logic is used to avoid obstructions.

Over the course of this engineering document, we address these problems, determine how we solve them, and explain the process which lead to these conclusions. Most notably, the development of a prototype robot allowed us to identify critical problems with our design and address them before implementation.

Additionally, the code which goes into this design will be explained.

Contents

1 Robot Design and History Overview

In this section, we detail each component of the robot, the design decisions that went into it, important and critical tests, and the general development of our design.

Over the past four years, our design strategy has changed significantly. We have gone through multiple paradigm shifts in our design process. Our first year, we simply threw ourselves at the problem and left the result to be decided. This worked wonderfully, but in retrospect, much of that was simply sheer luck. We struck the correct idea, and executed it effectively, but not to the best of our ability.

As a result, the second year, our effectiveness slumped slightly. Though we still won several awards for placing third in local competitions, we did not perform to our expected standard. The reasons for this are twofold: First, we failed to properly conceptualize what it is we intended to do before making an attempt at execution. In this way, the robot's design suffered significantly from problems which could have been solved with some forethought. Secondly, we failed to properly test the components of the design before implementation. We threw parts together without accurately testing each one for validity, and refused to change the parts that did not work.

We drew many lessons from that year, and in our third year, we developed a full SolidWorks model of our design, and created a defined intent for our robot before building. We prototyped several components before implementing them. We did still run into issues, but they were not issues we could necessarily have predicted or foreseen over such a short timescale. All things considered, we created a highly effective robot, breaking the world record score, and scoring a maximum of over 300 points on the field by ourselves.

This year, we had to think a bit more rigorously about our design. We hearkened back to the 2011-2012 FTC Challenge, "Bowled Over!" during which we struggled to actually lift the balls off the ground. We recognized going into this year that pulling objects out of a dispenser is much easier to design and engineer around than lifting objects off the ground. However, in the usual spirit of our team, we wanted to do it all. When we set out to tackle this challenge, we decided we would find the IR beacon, move to the bridge, score tons of blocks, raise the flag, and hang our robot. We decided that the challenge was *doable*, and we would meet its challenge. This, below, is what we have done...

1.1 General Structure and Design

We decided very early on what the style of our robot's design would be. We recognized that it is possible to determine some components' effectiveness without actually having *designed* the other components necessarily.

We started with the frame structure. We decided there were a couple main approaches: we could either lift blocks straight off the ground, or drive into blocks and lift them up that way. One way supports a high, square frame with a tall clearance, and the other supports an "A-frame," so called for its resemblance to a block-letter A. This would allow us to pick up blocks with the front of our robot, while still leaving plenty of room for electronics. We chose the A-frame over the square frame for sheer simplicity and potentially synergistic design with other components of the robot.

At this time, we had imagined the flag spinning motor on the front of the robot, an arm to manipulate blocks, and various motors and errata on the sides of the robot. While we have significantly changed the vision from its original form, it is still true to these aspects in particular. We have placed a flag spinner on the front of our frame, we have an arm to manipulate blocks, and the gears are stored in the side panels.

As optimal as we may have decided the A-frame to be, there were a few considerations to think carefully about before actual implementation. These were lessons we learned from "Bowled Over!". The first topic we needed to consider was stability. When we designed the frame for the challenge two years ago, we paid very little attention to stability. As a result, the weight we placed on the center of the robot caused it to cave in where it should not have. The front wheels warped inward, and the electronics came loose under tension. Additionally, the muli-segment arm had pressure in places it was not designed to support. We will reveal how we addressed this later in this section.

1.2 Considerations for Support, Structure, and Placement

We needed to make particular consideration for structure and weight distribution on the final design, as we had chosen a type of frame which becomes unstable if not properly constructed. We decided very early on that we would construct the robot mostly from raw materials, so the first consideration was of material. We were presented with several options, nobody on the team questioned the choice of Delrin as the appropriate material.

Material Selection Delrin was chosen primarily for its strength and resilience. It is an easy material to lathe and cut, both by laser and hand, and it does not damage easily. It is very strong in thick directions, and is also relatively lightweight. Tetrix aluminum frame pieces are far, far too flexible and pliable, and become warped or damaged easily during competition. Delrin does not often even so much as scratch.

Even so, we could not depend on Delrin entirely. After some consideration to structure, we decided that the easiest way to prevent the side panels from caving in was to both make them thicker and support them against each other. We decided that the wheels and gears could go in between two panels, which would be spaced for stability. These would act as our gear boxes. Additionally, the two gearbox panels would be supported by the entire middle section of the robot, which would prevent them from caving in. We decided support bars would be needed across the center of the robot. This, we decided, is doable.

Standoffs were used to support the two panels of the gearboxes.

Center of Gravity Some consideration had to be given to center of gravity. In deciding we wanted to use an arm, we effectively filled most of the robot with air. This made the center of gravity incredibly critical. It needed to be very low and centered, so that we could not possibly be pushed over by another robot. This meant that the motors powering the arm and wheelbase could not be placed adjacent to their respective components.

To demonstrate this, consider the placement of the motors. Place the front drive motors in the front of the robot, the arm motors up by the arm, and suddenly the weight distribution becomes horribly imbalanced. As a result, we decided to place the motors directly next to the electronics in front of the robot. The center of gravity is thus centered along the width of our robot, and sufficiently low to enable difficult tipping. We have encountered a slight problem, where the center of gravity is too far forward, but this can either be corrected or may not be an issue. We have yet to see in competition, but preliminary, informal tests indicate this may not be an issue.

Gear Strength We have learned from past years that Tetrix axles are insufficient for high load. This is a result of two parts: first, their circular design makes them hard to lock into anything. Second, the locking pin/set screw, under high tension, actually cuts into the axle, both preventing movement of the attached part and preventing removal. The axles also rotate under moderate torque, as they are made of aluminum.

In order to alleviate this problem, we are using allowed hexagonal axles. These have several benefits. First, they are much thicker, and will not bend or twist. Second, objects that are locked into a hexagonal axle cannot rotate freely around the axle. Third, the hexagonal collars do not lock against the axle themselves, and as a result do not create an indentation in the axle past which nothing will move.

Arm Support We decided the arm needed to be strong enough to lift the robot. During the construction of the first prototype of the arm, we created a way for the arm to support the entire robot, but miscalculated the shearing strength of the wooden collars which locked the arm in place. As a result, the torque on the arm caused by gravity caused the wooden collars to strip internally. We have since replaced them with custom-built clamps, designed after hex wheel hubs. More on arm design to come.

1.3 Wheelbase, Arm Design, and a small word about Flag Spinner

Wheel selection In selecting the wheels for our robot this year, we wanted to prioritize two things: maneuverability and traction. Wheel layout and selection is the entire deciding component in how these two motivations are balanced, and our wheel selection reflects this. We decided that our design model - block grabbing in front, dumping in back - necessitated finite control while aligning the back, but did not require such control in the front. We decided that the front needed to be able to turn quickly, and the back needed to turn precisely. These requirements fit the model of a "fish tail" drive perfectly.

A fish tail drive consists of two traction wheels and two omni wheels, mirrored horizontally across the robot. The traction wheels we used are called Colson wheels, and the omni wheels are standard Tetrix parts. We capitalized on the new lenience in wheel selection this year by selecting a wheel which is both smooth, large, and high friction. As a result, it is nearly impossible for another robot to push us sideways, and only possible to push us along the direction of rotation with compliance from the motors.

Arm History: Roller Our original intent with the design, as can be seen in the "Solidworks and CAD Modeling" section, was to include a roller in front which would bring blocks into the robot. We had originally settled on this type of design as it gave us the ability to draw blocks in from anywhere on the floor. However, this component had serious problems. To list a few:

- We could not pick up blocks at the corners
- It became very difficult to control the exact number of blocks we drew in
- It took up an egregious amount of space in the front of the robot
- It often failed to pick up blocks entirely
- It required significant machining to maintain and modify, as it is an entirely custom part that requires heavy maintenance
- It often picked up more than four blocks; there was no way to tell how many blocks it had, however, since the robot was visually in the way

These items forced us to reconsider this design decision. Upon reconsideration, we realized that we would rarely, if ever, have a need to pick blocks up off the ground, and that it was probably wiser to pick up blocks against a wall. After all, every one of the blocks starts against or adjacent to a wall.

Arm Block Scoop The block scoop came with two simple revisions. During the first revision, we intended to create a small ramp, which the blocks would fall over when we hit them. This worked well, but did not work entirely as we intended. We noted a couple difficult problems, which would cause delays in the way we work in teleop. The first was that we had a chance to grab more than five blocks, and the second was that it required significant force to actually climb over the ramp.

To solve these problems, we took two actions: First, we replaced the solid Lexan panel with a thin sheet of plastic, which was thin enough to consistently slip underneath the blocks while also being able to support blocks. The second change was to add a metal bar to the inside of the arm, which prevents us from grabbing five blocks. With these two changes, we now consistently grab four blocks, even when there are very few blocks remaining at the edge of the field.

Robot length While one might normally consider this to be a small or trivial detail in robot design, this actually grew to high importance for us in our design deliberation. There are a couple reasons for this: first, fish tail drive is significantly impacted by the span of the wheels. Too short, and the robot does not turn well. Too long, and the front turns too quickly.

We have additional constraints on our length as well: we need to 1) be able to support a flag spinner in front of the robot, which cuts a couple inches off, and 2) we need to be able to pick up blocks with the front of our robot. Our initial design for a roller necessitated a much larger margin in the front of the robot, however, as that has changed, the length of the robot changed with it.

Flag spinner This deserves an honorable mention. We used the dead space on the back panel to add a wheel with two prongs. We originally wanted to use a rubber panel and friction to turn the flag spinner, and our first tests told us this would work. However, in practice, it was too difficult to align, and was replaced with two prongs.

The rotational motor is geared 1:3. This is satisfactory, and provides a lift time of 4.5 seconds, which is good enough for our purposes.

2 Meetings and Proceedings

In this section, we detail exactly what happened at select meetings, whose events bear particular significance over the development of our robot.

2.1 Preseason Overview – Meeting 1: 2013-08-31

We held a preseason meeting in order to go over scheduling, recruitment of new members, and hold a quick review of what we learned from our last season. One of the main items we discussed was our scheduling, and as a team we decided to take an aggressive approach towards our first couple of regional competitions in order to secure a place in St. Louis. Because of this, we may need to cut back on scoring the maximum number of points and instead focus on scoring a high, yet consistent number of points. We found out that we need to secure our electronics and work with the field control issues that we were issues. We also plan on placing a much larger emphasis on the CAD design of our robot than we have in our two previous years as it is an efficient way to quickly discover and troubleshoot problems prior to building the system.

Our final goal is to have two weeks of drive practice before our first regional on December 14th, important for both driver and coaches, to figure out the timing of the game, as well as things that we can or cannot do in game. Organization of the team this year will be facilitated through the use of Google Groups, which will allow all the team members and their parents to be easily contacted for meetings, and will hopefully foster some discussion over build design or game strategy.

We also decided to meet a few hours after the game was released next week so team members could think about strategies ahead of time and add to the strategy discussion of our first meeting of the season. The meeting was fairly short, but got the team in the right mindset for the upcoming season, and got everyone excited for the new season!

2.2 Initial Design – Meeting 2: 2013-09-07

The team decided last week to meet a few hours after the game video and rules were released, so by the time our meeting started, everyone had an idea of how they thought the robot should work, and be built. Fortunately, most team members were on the same page and wanted to focus on scoring as many blocks into the baskets as possible, in a manner that would allow for a integration in the lifting and scoring mechanism. We decided to focus on every aspect of the game for our qualifiers, since it seems like we could consolidate all of the mechanisms into very few.

After a fairly long strategy discussion, some ideas were thrown around as to how to pick up and score the blocks, since we always have a difficult time getting our game pieces, and a rough idea of a mechanism was developed that would use a roller system and a block hopper that would pick up and score the blocks. There is still significant discussion considering the way we will go about constructing a lifting mechanism, with different arguments for and against a rotating arm and a more standard but perhaps less efficient forklift, similar to "Ring It Up!". Some of our team members have some experience with constructing forklifts from prior FTC seasons, so we have some idea of what kind of issues we might come across with that kind of design. One thing we discussed was making sure we construct and purchase our materials with a little more regard for quality than we have in previous years, but we wanted to focus on simplicity this season as it worked out very well for us three years ago, and the ideas we are thinking of currently all seem to fit this idea.

Members of the team have assumed different jobs to complete before the next meeting, such as researching lifting mechanisms, getting a BOM for the field and purchasing the materials, and researching the specifications of an IR beacon and sensor, since the team also decided that scoring the block during autonomous is absolutely imperative to the outcome of this game. It is essentially free points that even a defensive robot cannot stop. As of right now we are choosing to focus the endgame period, since lifting and raising the flag are relatively simple tasks.

We are considering purchasing the AndyMark field, as it would provide us a standardized field and a better replication of the interaction of the robot with the field during competition.

2.3 General Design – Meeting 3: 2013-09-14

Today was our second main meeting; we discussed several different raising mechanisms, since we as a team have decided that it was the most important system of our robot.

Our main idea for lifting is an arm that is centered around the top corner. We are designing it to be just long enough to allow us to climb the bar as well as to clear the front block scooper. As for the material, we were looking at Delrin, and wood for our prototype. Delrin has incredible tensile strength. If a material is homogeneous then the tensile and flexural strengths are identical. However, most materials have defects in them which act to concentrate the stresses locally, which in turn cause a localized weakness. We have determined that the flexural strength is greater in the Delrin over the wood as follows. We first see that method for calculating flexural strength is:

$$\sigma = \frac{3FL}{2bd^2}$$

and we are looking to see which sheet can take in the maximum force, F. It directly follows that as we increase b, the width measured in in, and d, the thickness measured in in, the sheet can withstand a greater force. Elementary analysis allows us to see that the Delrin is superior than the wood. This will assure us that if our wood prototype works, so should our final design. It will also be able to withstand in competition.

For the flag spinner, we discussed using some external pins or some type of rubber-esque substance to push against the edge and raise it up. We believe that a rubber-esque material will work. We plan on using 3 NXT motors to provide enough torque and speed to raise the flag. Our goal is to raise the flag in under 5 seconds.

We also spent a lot of time discussing the importance of autonomous and the structure of our code. We are looking at dynamic autonomous programs that are able to dodge other robots if need be. We are looking forward to prototyping within the next several weeks. Our meetings have mainly comprised of theorizing about code and 3D modeling our robot. We are sharing with the younger students much of the knowledge we have learned over the years as well.

2.4 Initial Field Build – Meeting 4: 2013-09-21

Today we began building the field, discussed the lifting, got mail, worked on autonomous theory, cut PVC with safety glasses, and had some fun moving our very mobile robot for a while. In the mail we received one half of the blocks necessary for the field. For building we:

1. Painted the wood
2. Cut all the pvc pipes for the flag spinner
3. Wore safety glasses
4. Cleaned up a lot of pvc dust
5. Screwed temporary screws to the flanges onto the wood

Flag Spinner:

- Involves NXT motors
- Gearing 6:1
- Rubber-esque material did not work out
- Using extruding pins

2.5 First Prototype – Meeting 5: 2013-09-28

Today was a day for laying out drawings, finalizing designs, and testing some of the flag spinner prototypes.

We started the day with the usual bit of socialization, before returning to work. The primary topic of discussion is the acquisition mechanism for the blocks. It has been speculated up until this point that we are going to be using a roller, and it looks like those plans may come to fruition. We received several items today, including some Tetrix motors, as well as M3 screws and the other half of the blocks.

A to-scale side view drawing shows that the arm we want to design and guiding channels will take up about 7 inches on either side, leaving 8 inches in the middle to mount the block grabbing mechanism on. This fits within our expectations.

It is worth noting that the since we are designing the robot out of raw materials we are using metric, as opposed to the imperial u-channels, so there is some difficulty in lining up the holes if we plan to use any Tetrix. This is a prototype however, and the arm we plan to design for the final design would be out of Delrin, and can be designed to fit our needs. The prototype wooden arm also has potential tolerance issues. There is about a 1 block tolerance on the size of the spinning blocks. Stability is key.

We constructed our first prototype, we assembled the outside arms from plywood. From left to right, there are two arm chassis pieces, the arm pieces and then two arm chassis pieces. The frame design is an A-frame and it works pretty well.

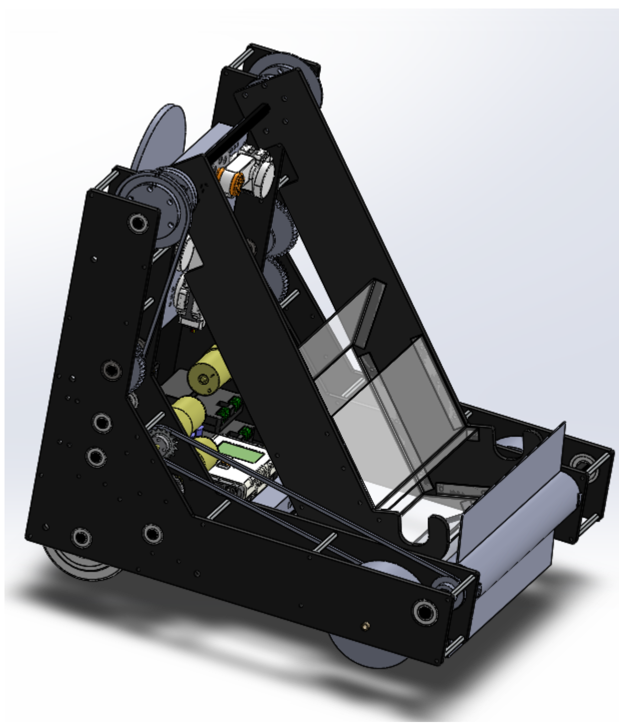


Figure 1: This is the first revision of our Solidworks. We can see the block acquisition device that is essentially a roller that will inhale blocks into our robot

Force is not an issue, and remains at a 16:1 ratio with torque gained. It is important to note that the force DOES double when an additional layer is added, however, with the 16:1 ratio between the movement of the bars, the speed with which the bars are raised ALSO doubles. This means that, though the force doubles, the speed at which the arm go up is also doubled. That implies that any torque issue created by adding another layer to the mechanism can be resolved by multiplying the gear ratio of the chain motor by two. The same vertical speed will be achieved. The prototype is very functional. We connected it to the (makeshift) motor, and ran it. The mechanism lifted very well. The following problems were noted:

- Block pickup does not work
- Lifting does not lock after power is lost
- The wooden shaft collars strip
- It does not move fast enough
- It makes the robot very back heavy

Possible solutions to these problems (in order) are:

- Switch from the roller
- Jam the gears
- Change the wood to metal
- Add steel to the front

Despite these issues, the lifting mechanism works well, and glides smoothly as long as they aren't stripped. Granted it is currently in prototype form, the final version (which will be produced much more carefully), should be very effective.

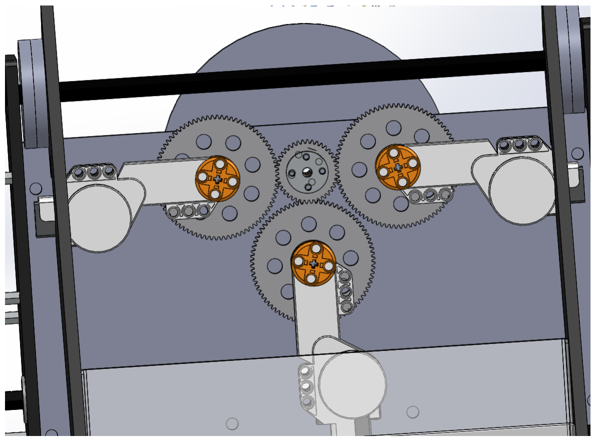
We are currently looking into redesigning the block pickup mechanism as it does not seem to be effective. We plan on lowering the roller to the ground and seeing what happens.

Currently, our projected maximum height is 32, just over what we need to hang on the bar.

2.6 Flag Spinner Initial Test – Meeting 6: 2013-10-6

Today's meeting was short - it was only two hours. We had a couple ideas we wanted to test, and the tests were successful. We verified our idea would work, and redrew the pictures from two days ago.

The idea we were testing today was whether or not we could raise the flag by using a rubber-like substance to mesh within it and spin. We soon saw that the NXT motors were not as powerful as we would like and the force that the rubber plate was inducing was off center. This makes it unfeasible to use.



We plan on switching to the seemingly common extruded pins design. We plan on having two pins attached off center that are 180° apart. We also plan on switching to a Tetrix motor with a 6 : 1 gearing ratio. With this ratio, we will be able to raise the flag, theoretically, in under 10 seconds.

However, this method adds an extra 1.5″ to our length. As we must stay within the 18″ length constraint, we may have to shorten our roller (block pickup mechanism). This may become problematic, but as far as we can see we should be able to work around it.

For the pins, we had two ideas: the first is to use cut Tetrix axles. The second is to use longer Tetrix screws. We plan on using the Tetrix screws first to test and we may end up keeping them on afterwards.

We also did some more testing with the roller. We experimented with lowering it and shrinking the radius of the aluminum tube. We chose a smaller inner radius due to the fact that it would weigh less and it would be easier to place near the ground. We are still running into issues of picking up much more than 4 blocks at a time.

We decided on mounting it 1.5" above the ground because this is just enough to let the blocks slide under as we roll.

It is the popular idea that we want to completely redesign the block grabbing mechanism due to its inability to give us the accuracy and visibility that we want. Visibility is an issue when we go to the opposite side of the field.

2.7 Block Acquisition Redesign – Meeting 7: 2013-10-11

We have spent a lot of time working on scoring blocks, but we overlooked the difficulty of acquiring them. We decided to spend the day looking over our acquisition device as we found it was not very effective. We are looking into changing the roller into a much lower roller made of rubber. We are also looking into changing the entire design altogether. The main ideas consist of driving into blocks and then flipping them into our arm. However, many members of the team do not like the idea of multiple moving parts.

We decided to extend the final aspect of the roller and found that it was completely ineffective. There is currently no member that continuously supports this idea.

Today, Garrison proposed that we use a bulldozer like system. A flat plate that we would use to ram into the blocks. Essentially extending our arm to be outside of the frame. We built a first prototype with this and it seems to show some promise. We are still unsure of the implications that this has for the a final working idea.

Another issue we see with this mechanism is that it is very easy for blocks to slip outside of our robot.

We currently plan to go home and think about better ideas. We will probably have an in-depth Skype conversation over this idea. We look forward to improving this design as it needs a lot of work.

The flag spinner was also entirely redesigned as follows:

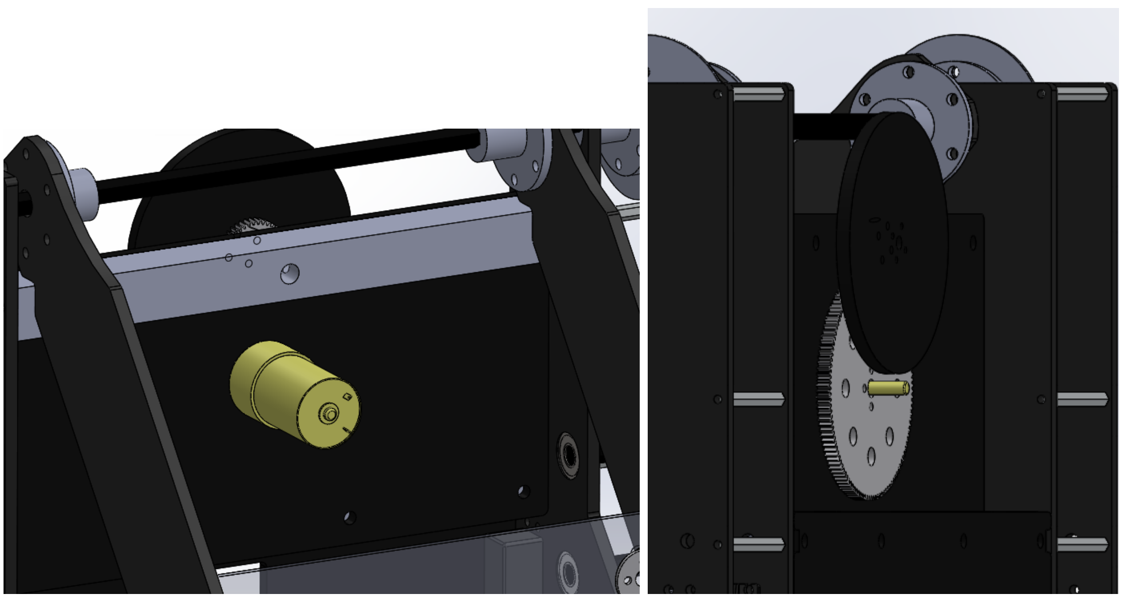


Figure 2: Here we can see both sides of the new, redesigned, flag spinner. The notable changes include the switch to the Tetrix motor and the removal of the rubber backing in turn for extruding pins (not shown above).

2.8 SolidWorks Redesign – Meeting 8: 2013-10-18

After coming back with new ideas, we spent the first hour of our meeting discussing the pros and cons of our new block acquisition mechanism. We all feel that a flat sheet on the ground that we can use to run into the blocks as a bulldozer is the optimal solution.

We are designing it to be fully flush with the ground. We look forward to testing this out. In SolidWorks we are redesigning the base of the robot to be shorter to allow the bulldozer system to lie in front.

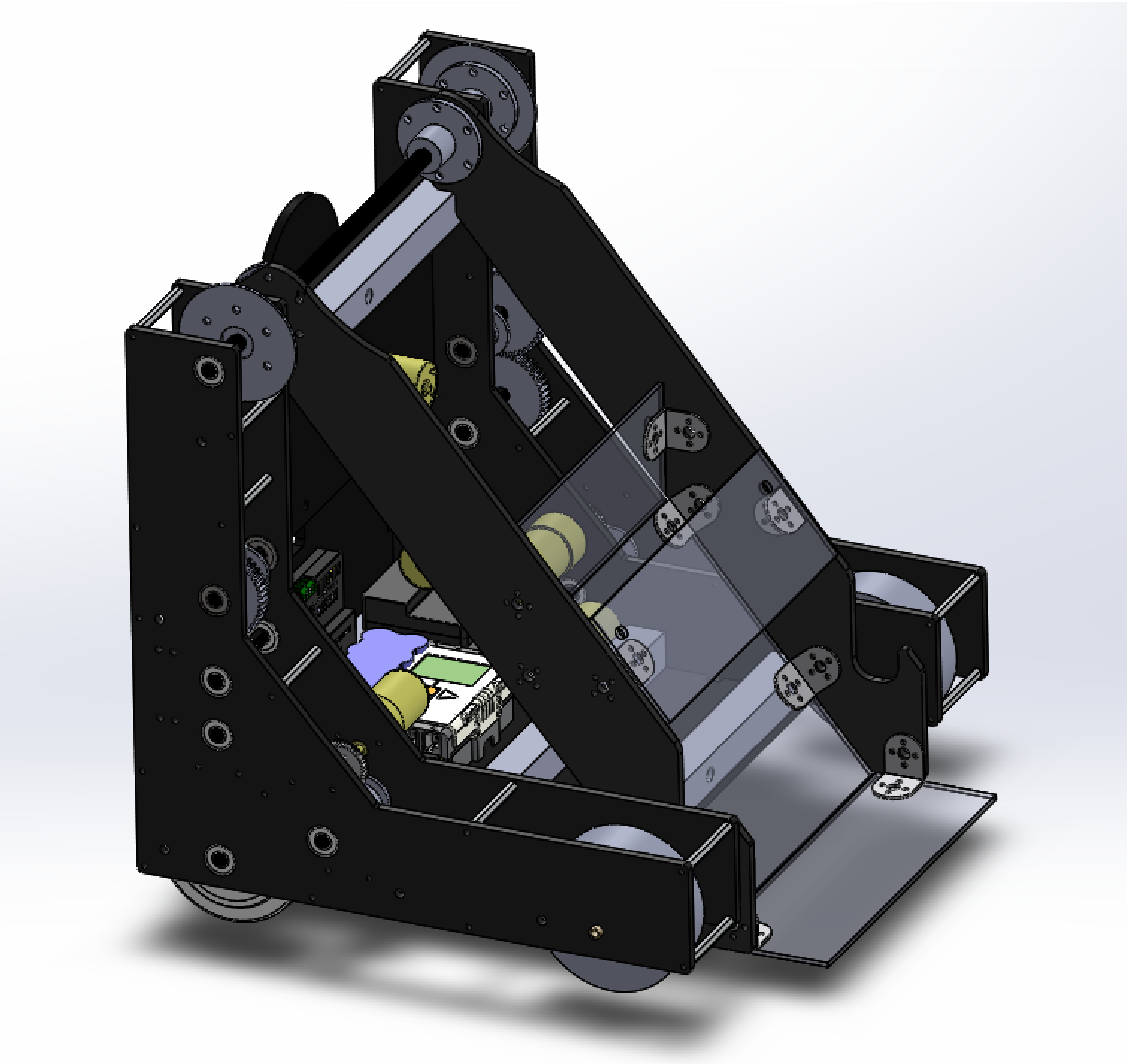


Figure 3: This is the second revision of our SolidWorks which includes the redesigned block acquisition device.

2.9 First Full Test and Match – Meeting 9: 2013-10-25

Today was our first day having a fully complete robot. Although we had done several tests of our prototype before, this was the first day we had everything working together. The excitement within our team was immense. We tested our drive train with the added weight of the arm on the motor. We tied the flag mechanism with nylon as our Kevlar rope has not yet been received. The Kevlar provides less friction and is more like the competition.

Near the bottom, we have a lot of empty space to place the electronics. We hope to use the HiTechnic SuperPro this year to do much more sensor fusion. We want to add an Arduino or Atmel processor (ATUC3b0128) to do much more powerful computation without having to deal with the timing issues that are imposed by using the task system in RobotC and the slow clock of the NXT. We have plans to include gyroscopes, accelerometers and ultrasonic sensors. We are also looking into developing our own infrared seeker, although we are still uncertain about the feasibility of that task.

With the A-frame design that we have we are able to distribute all of our weight to the back of the robot. This makes it very stable and very difficult to push us.

When we scored our first block, the entire team was ecstatic. We all felt relief that we were able to lift something and score our blocks. We were somewhat surprised as to how simple it was for us to score a block. It went on just by driving backwards and raising the arm.

The arm went up very smoothly and we had no issues scoring on any of the blocks. We decided to play our first match to see how many points we were able to score.

We gave Tristan the controller and on our first run we were able to score about 200 points. We scored only on the outside baskets. This added up to the balanced bonus bonuses. Overall, we are very happy with the current design of the robot. Although, we do feel that a lot of driver practice is needed, along with an improved block acquisition device.

Once we had the entire robot built we started testing the arm mechanism and it's ability to remove and score blocks. We found that although it is just in and out straight, moving linearly. We also found that it requires almost no effort to manipulate.

Tristan, our driver, says that with the new Fishtail drive train that we incorporated along with the ease of use of scoring blocks and removing them from the ground. We are still unable to consistently pickup 4 blocks.

There is an air of reminiscence from our first year of FTC. We feel that our strategy and simplicity of our mechanism is very similar. This brings back memories to the members who were on the team from the conception of the team. This also brings an air of confidence among the members about the ability of our robot.

Now there is a lot of talk among the team members about autonomous and strategies for approaching it. We have the ability to determine which column the Infrared beacon is one within one second of our robot starting up.

After we scored our first block and played our first game we decided that we had accomplished a decent amount for this extra Sunday meeting and decided to call it a day. We have high hopes for the competition and expect to place well at our first qualifier.

2.10 Short Design Meeting – Meeting 10: 2013-11-2

Today was mostly a day for driver practice and minor repairs. We did several hours of practice, then moved the grabbing mechanism down an inch because it was barely outside the sizing box. This created a couple functionality issues, which will be resolved in the next meeting. We also tested the autonomous accelerometer and gyroscope, but didn't get much farther than measuring the (mostly insignificant) error before we had to leave.

Today was short.

2.11 Tweaking and Autonomous Programming – Meeting 11: 2013-11-8

Today several mechanical changes were made. The flat block grabber was moved down more, but the attached aligning bars were kept in the same place. The bars were also melted into a curve to stop the blocks from catching on them, but at the same time keeping them from falling out. In addition, we made our hex arm shafts, designed after the AndyMark hex wheel shaft. We used a lathe to create the same shape and then used a hex broach of 3/8" to allow it to slide over.

Another notable change was somewhat small, but it was entirely necessary. We added a funnel like system onto our arm to stop blocks from flying out as we tried to score. This was done with two small bent Tetrix pieces that redirect the blocks into the center of our scoring mechanism.

After implementing this, the amount of blocks that we missed dropped from almost 50% to nearly 2%. This worked phenomenally and outdid all of our expectations.

Today was a rather complex code day. Yousuf and Kian woke up early to start work at 7 AM on autonomous. Other team members were arriving past 10. Our progress was significant and extensive, leading us into a few minor problems but also into several solutions.

We decided immediately to write the code again from the bottom up, testing each component as we added it. The old code would have taken too long to get working properly. We struggled for around half an hour with a few simple glitches. We had a very silly error where RobotC simply refused to function properly. The eventual solution was ridiculous: the line of code with the error was replaced via copy and paste with a duplicate line from an old code file. This resolved the issue.

Accelerometric integration now works, and we can properly integrate our position with very little noise and error. There are no issues here.

The gyroscope integration, on the other hand, is returning garbage output. It's moderately representative of our actual rotation, but in actuality it is totally useless. The tolerance is +/- 10 degrees. I surmise this is a tasking issue, and δt is not being set properly, resulting in error.

We attached the infrared seeker sensors, and can now start the game consistently knowing which column the tag is in. We have a 540 degree field of view, since the two sensors face opposite directions. As such, our first movement command is to go directly to the column with the IR beacon. We may need to redesign our autonomous though since we are getting a lot of noise.

Our plan is to turn perpendicular to the pendulum. Everything except the gyroscope is functional.

2.12 Autonomous Working (No IR) – Meeting 12: 2013-11-10

This weekend, we successfully programmed our autonomous. The code allows the robot to deposit the autonomous block in any basket, as selected by the user interface. The logic for this decision works as follows:

- The user selects which row they would like the block placed in, if the IR beacon is in each column.
- The robot uses triangulation with two outward-facing IR seekers to start the game immediately knowing which column contains the beacon. (This still doesn't work yet)
- The robot angles to the correct basket.
- The robot moves and rotates, aligning itself to score with the block.
- The robot raises the arm, scoring the block.
- It then backs off to move onto the ramp.

The program for this has been written, and works with an (approximated) 90% consistency.

2.13 Driver Practice and Lifting Locking – Meeting 13: 2013-11-17

The plan for the meeting was to spend an hour or two testing the autonomous for consistency at getting on top of the ramp. Then the plan was to do driver practice for the rest of the day.

Early tests of the autonomous showed some problems getting on top of the board, with the placement of the sensor being off about 30% of the time. The most common issue occurred when the IR mounting was off center. This caused us major error. After mounting the beacon much more securely, the autonomous became very consistent at getting to the pendulum, scoring the vast majority of the time in several trials.

As we began driver practice, however, some structural problems were discovered. The cross bars that we were using to brace our lift torqued during one run, causing us concern when lifting. Tristan volunteered to create the crossbars in SolidWorks and spent some time taking careful measurements of the spacing between the two halves of the lift. The other major fix that was incorporated was to add two points of contact on each side in order to stop the arm from torquing under major force.

We also developed a lifting locking mechanism which works by jamming a third gear into our system. This induces a lock that cannot be broken and does not need power. Figure 4 shows this system in action.

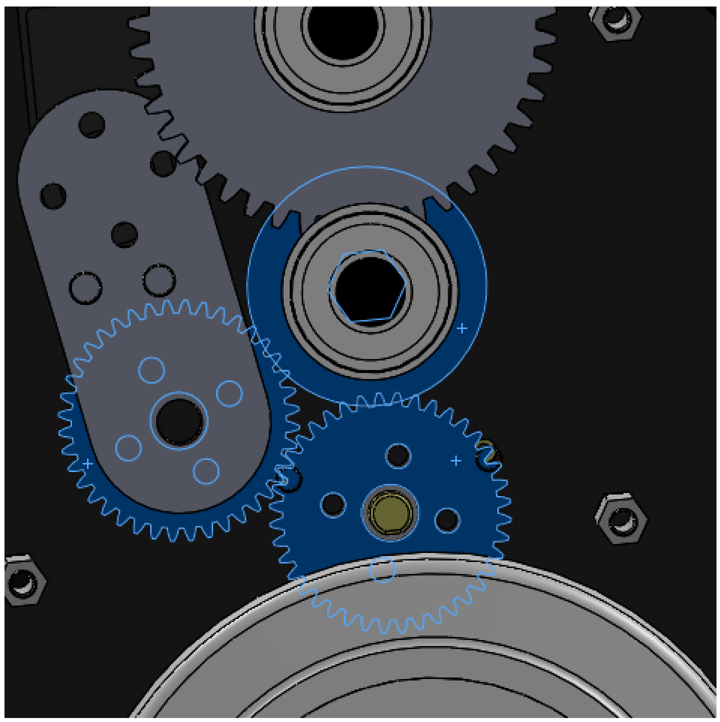


Figure 4: The blue sections highlighted show the three gears that are all locked together. It restricts any movement and works effectively.

2.14 Outreach – Meeting 14: 2013-11-29

This year we decided to mentor an FLL team and we mentored two FLL teams. We helped them program the new EV3 and taught them some new design techniques for the attachments that they had on their robot. We spent about 4 hours running through all of the programs they had and suggesting different ways that they could go about it. We also taught them how to use sensors as a lot of their programs were unreliable. We hope to start an FTC team with these students in the upcoming years. The FLL team we mentored just won their qualifier competition and has a regional competition at LegoLand on December 7th.

2.15 Driver Practice – Meeting 15: 2013-12-6

Today we mainly tested our robots abilities using time trials. Our robot managed to pick up two to three blocks per trip, which was below our expectations. Because of this we began experimenting with different methods of collecting blocks, such as a horizontal roller. The first material being a sheet of extremely thin sheet metal which was low enough to the ground but it was too weak, When we tried to pick up blocks the metal would buckle and make a wall impossible for anymore blocks to get up. Our next solution was to use a thicker, flexible sheet of plastic that slid with really low friction across the ground. The plastic sheet was just the right height to where it would fit perfectly under all of the blocks without getting deformed.

Our next task was to be able to fit three or four blocks, no more no less. The way we solved this greatly important problem was by using a metal deterrent to block more than five blocks from being collected. The combination of the ramp and the deterrent made it so that we extremely rarely picked up two blocks but we also very rarely picked up more than four blocks.

Overall, we are currently scoring approximately 300 points alone per round. We hope that our speed will be unmatched and we will be able to score many points.

3 Software Architecture and Implementation

Detailed in this section is the method and reason to our software architecture. In particular, we aimed for our architecture to be stateless with respect to the current operation, to maximize efficiency of joystick checks (which are normally slow in RobotC), and to allow dynamic and easy reassignment of both controller information during teleop, as well as both movement sequencing and heuristic decision trees during autonomous.

We have chosen a particular structure for our code. We have rewritten `JoystickDriver.c` to better express our needs. By removing superfluous tasks from the driver, we maintained functionality while increasing our efficiency by approximately threefold. We have created a set of utility headers: `teleoputils.h`, `autoutils.h`, and `sharedutils.h` to address the need for macros, `#define` statements, and standardized functions. Both `teleoputils.h` and `autoutils.h` import `sharedutils.h`, so that file is never explicitly included in the main code body. Drivers were pulled from HiTechnic's online library for 3rd party sensors.

3.1 Teleoperated Mode

Teleoperated mode has the following requirements:

1. Smooth arcade driving
2. Easy reassignment of buttons
3. Stateless control of motors and robot state
4. Efficient button control and loop checking
5. **Must** use only one controller

In order to implement this effectively, we have implemented several macros. These macros allow us to later set the powers of the motors without much effort.

3.1.1 Drive Code and Reasoning

Our main body of code is run through the following:

```
task main() {
    while(true) {
        getJoystickSettings(joystick);
        checkJoystickButtons();
        setLeftMotors(powscl(JOY_Y1)-powscl(JOY_X1)/1.75);
        setRightMotors(powscl(JOY_Y1)+powscl(JOY_X1)/1.75);
    }
}
```

First, grab the current joystick configuration from the controllers. Then, check to see if any buttons have changed (`checkJoystickButtons();`). Then, set the motor powers for arcade drive.

Power scaling The `powscl(int)` function's definition is intended to compensate for the large deadband range which occurs under standard drive conditions. The controller's user really only needs two ranges: a high-precision, low power range near zero, and a low-precision, high power range near the maxima. While an exponential function could be used, it is much slower, and much more hard to tune. Instead, we draw two lines: a shallow slope for the first segment, then a large slope for the second segment of the controller. This provides both high precision and high power where needed. As the driver does not generally use the range in $[60, 85]\%$, there is no concern about the nonlinearity. The function is defined as follows:

```
float powscl(int xz) {
    float sign = (float)sgn(xz);
    float x = abs(xz)/128.0;
    if(x < DISTA)
        return 100* sign * (x*SLOPE);
    else
        return 100* sign * ((DISTA*SLOPE*(x-1.0) - x + DISTA) / (DISTA - 1.0));
}
```

Compensation for the Old and New Joystick Configuration It is necessary to compensate for both the old and new controller configurations. As the controller has been updated, the buttons have changed - however, competition rules permit the use of both controllers. Therefore, we must be able to accommodate this change if necessary. We have done so through the use of a define statement: if we have `#define ALTLOG`, then we switch to the old button layout.

Button Press Checking Requires a Stateless Organization In order to easily and effectively change the functionality of the controller, a particular design was implemented:

```
void invokeButton(int button, bool pressed) {
    switch(button) {
        case JOY_X:  if(pressed) {servo[servoL1] = 156; servo[servoL2] = 26;}
            else {} break;
        case JOY_Y:  if(pressed) {servo[servoL1] = 120; servo[servoL2] = 40;}
            else {} break;
        case JOY_A:  if(pressed) {} else {} break;
        case JOY_B:  if(pressed) {motor[mSpin] = 100;} else {motor[mSpin] = 0;}
            break;
        case JOY_RB: if(pressed) {setArmMotors(100);}  else {setArmMotors(0);}
            break;
        case JOY_LB: if(pressed) {setArmMotors(-100);} else {setArmMotors(0);}
            break;
        case JOY_R3: if(pressed) {} else {} break;
        case JOY_L3: if(pressed) {} else {} break;
    }
}

bool t[8];
void checkJoystickButtons() {
    for(int i = 0; i < 8; i++) {
        if(joy1Btn(i) != t[i]) {
            invokeButton(i, !t[i]);
            t[i] = !t[i];
        }
    }
}
```

This may appear confusing at first, however, there are a couple points: `checkJoystickButtons()` is actually called from the main loop. It simply checks to see what buttons have changed on the controller, and calls the appropriate `invokeButton(int, bool)` arguments. In doing so, we can determine exact behavior on button presses with ease. As our robot is very simple, we do not need more than a handful of buttons, so most of them remain unassigned.

Code Optimizations Although this method works for determining which button is being pressed, we quickly found it is not the most elegant way of doing so. First off, we use a `bool[]` to hold the state of each button. This seems intuitive, but the RobotC compiler actually creates an entire `char` to hold either `true` or `false` for every `bool`; this is a waste of memory. The other issue can be found in the processing structure. Each iteration of the program checks all possible button conditions; this is a waste of processing time if there has been no change since the last iteration.

```
short btn = JOY_BTN;//local store = live store, initially
void checkJoystickButtons() {
    if(btn == JOY_BTN) return;//checksum
    for(short i = 11; i >= 0; i--) {
        if((btn>>i) ^ (JOY_BTN>>i)) {//check each button for a change
            invokeButton(i, ((btn & (1 << i)) == 0));//trigger event (#, down|up)
            btn ^= 1<<i;//mirror changes in local store
        }
    }
}
```

We solve the former issue by means of storing each button state in a single bit of data, reducing our memory footprint. Teams are encouraged to call the `joy1Btn(int)` function each time they wish to check the state of a particular button, but this can become cumbersome of one wishes check multiple buttons in real-time. The "JoystickDriver.c" file that we must use for field communications stores each button state in a single `short`; this means that we are capable of running a checksum of the joystick state before we check each button. This not only reduces our time per iteration, but also allows for our robot to be more responsive to joystick changes due to the inherent speed of bitwise operations.

3.2 Autonomous Mode

Autonomous, much like teleop, must meet certain criteria:

1. Recognize which crate has been chosen with the IR beacon
2. Move to said crate in a timely manor
3. Move to onto the bridge after scoring our block
4. Avoid any other robots on the way

Crate Detection Much like any other team, we use the HiTechnic IR Seeker to determine which crate our robot should pursue. We use a function that reads not only the position of the IR beacon relative to our location on the field, but also the strength at which it is reading. Having more than one variable to check greatly reduces the generally unavoidable environment-error the comes hand-in-hand with Infrared Light detection.

Movement Functions Using motor encoders, sensing how far a robot has moved is relatively simple in theory. Generally, the code becomes messy when the programmer has to remember motor encoder values and direction. To solve this issue, we have implemented general movement functions based on inches.

```
void rbtMoveFdTime(float inches, int msec) {
    int enc = getEncoderByInches(inches); clearEncoders();
    int norm = -1.0*sgn(inches);
    ClearTimer(DrTimer);
    while(leftEncoder < enc && rightEncoder < enc && time1[DrTimer] < msec) {
        setLeftMotors (100*norm);
        setRightMotors(100*norm);
    }
    setLeftMotors(0); setRightMotors(0);
}
```

This function allows our robot to move forward by a arbitrary number if inches and finish the motion in less than the specified time. Generally one does not want to move forward for an amount of time because the power fluctuates with battery levels. On the same hand, if one moves forwards based on just encoder values, the motor have the potential to burn out if the robot incurs a collision. Allowing the function to reach the specified distance before a certain amount of time insures that neither of these situations have a high probability of surfacing.

Object Avoidance Through the use of the HiTechnic SuperPro that was made legal by this year's game manual, we have been able to mount a high performance ultrasonic sensor to validate that the path we wish to take is open. If there is an obstruction, the robot moves onto the bridge via an alternate route. This feature increases the probability of a higher average score.

```
bool pathClear(float dist){
    pause();
    float read = 0;
    for(int i=0;i<10;i++){read+=(analogRead(A3)*0.4);wait1Msec(5);}
    nxtDisplayBigTextLine(3,"%f", read/10.0);
    wait1Msec(2000);
    return ((read/10)<dist?false:true);
}
```

3.3 Algorithms and Cartesian Mathematics

3.3.1 Hybrid Localization Using Gyroscopes & Odometers

Odometric Data We begin by assigning the following constants:

$$D_{ot} = \frac{\text{Distance}}{\text{odometer tick}} = \pi(\text{wheel diameter})/(\text{ticks/revolution})$$

$$\theta_{ot} = \frac{\theta}{\text{odometer tick}} = \pi\left(\frac{\text{wheel diameter}}{\text{distance between wheels}}\right)/(\text{ticks/revolution})$$

We can calculate $(x_{\text{enc}}, y_{\text{enc}}, \theta_{\text{enc}})$ from the odometer as follows:

$$\begin{aligned}
\mathrm{d}l &= l_{\text{enc}}^{t} - l_{\text{enc}}^{t-1} \\
\mathrm{d}r &= r_{\text{enc}}^{t} - r_{\text{enc}}^{t-1} \\
\mathrm{d}D &= \frac{1}{2}(\mathrm{d}l + \mathrm{d}r)D_{ot} \\
\mathrm{d}x_{\text{enc}} &= \mathrm{d}D\cos(\theta_{enc}^{t}) \\
\mathrm{d}y_{\text{enc}} &= \mathrm{d}D\sin(\theta_{enc}^{t}) \\
\mathrm{d}\theta_{\text{enc}} &= (\mathrm{d}r - \mathrm{d}l)\theta_{ot} \\
x_{\text{enc}} &= x_{\text{enc}}^{t-1} + \mathrm{d}x_{\text{enc}} \\
y_{\text{enc}} &= y_{\text{enc}}^{t-1} + \mathrm{d}y\text{enc} \\
\theta_{\text{enc}} &= \theta_{\text{enc}}^{t-1} + \mathrm{d}\theta_{\text{enc}}
\end{aligned}$$

l denotes the left side of the robot, and r denotes the right side of the robot. D denotes the distance.

Localization Algorithm The robots motor controller calculates position and orientation $(x_{\text{enc}}, y_{\text{enc}}, \theta_{\text{enc}})$ from encoder ticks and sends the data to an on-board computer. The mounted gyroscope communicates with a gyro driver which integrates the rate values into an absolute angle (θ_{gyro}). Global position $(x_{\text{rbt}}, y_{\text{rbt}})$ is found by transforming the translation vector from encoder space to gyroscope space. Global angle (θ_{rbt}) is the gyro angle (θ_{gyro}). The following describes the computation as an iterative algorithm:

$$\begin{aligned}
\mathrm{d}x &= x_{\text{enc}}^{t} - x_{\text{enc}}^{t-1} \\
\mathrm{d}y &= y_{\text{enc}}^{t} - y_{\text{enc}}^{t-1} \\
\mathrm{d}\theta &= \theta_{\text{gyro}}^{t} - \theta_{\text{enc}}^{t} \\
x_{\text{rbt}}^{t} &= x_{\text{rbt}}^{t-1} + \cos(\mathrm{d}\theta)\mathrm{d}x - \sin(\mathrm{d}\theta)\mathrm{d}y \\
y_{\text{rbt}}^{t} &= y_{\text{rbt}}^{t-1} + \sin(\mathrm{d}\theta)\mathrm{d}x + \cos(\mathrm{d}\theta)\mathrm{d}y \\
\theta_{\text{rbt}}^{t} &= \theta_{\text{gyro}}^{t}
\end{aligned}$$