"Cyber Swerve Project"

Implementing a Swerve Drive System

Project By
Cyber Blue - FRC 234
Summer 2009 – Spring 2010

Report By
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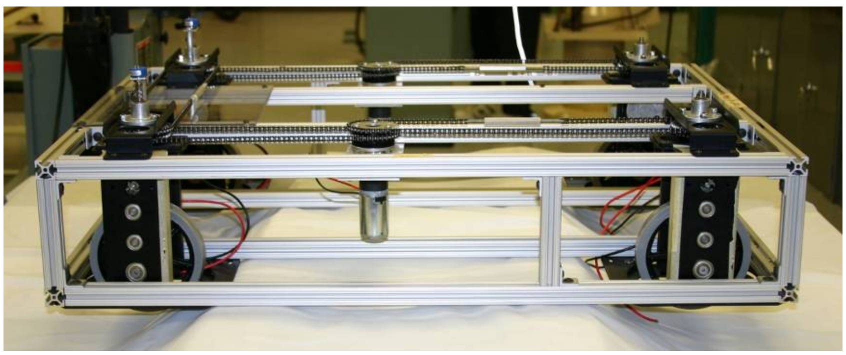

Cyber Swerve

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Cyber Swerve

SECTION I – BACKGROUND AND DEFINITIONS

Background

Cyber Blue has been interested in creating an omni-directional drive for several years. Based on our understanding of the drives, and discussions with other teams, we knew that our best option for success would be to develop a system in the summer and fall, and that it would be very risky to try to develop a new drive capability during a build season, while also trying to build a robot system to play a new game challenge.

During the spring of 2009, the team decided to make an omni-directional drive system a summer and fall project, and the team began looking at other robots and other designs at FIRST events and in online forums. The team did considerable “scouting” at the 2009 Championship event, including attending a presentation on swerve / crab systems from Team 118, the Robonauts.

Starting in June 2009, Cyber Blue began the process of developing their system. The team goal was to develop a drive and chassis system and have enough experience with driving and controlling the system that it would be available for use in the 2010 FRC season, if warranted by the game.

As with many team projects, there are a few companies and individuals that supported our project. There are more details at the end of this paper, but we would like to acknowledge Team 118, Team 111, Team 221LLC, Andy Baker and 80/20.

History – Basics

FIRST robots are similar to other products and other product families in that many teams create new and innovative systems that are then refined and improved by other teams. Often, these initial models become so widespread that they become a “standard” in FIRST, with many becoming commercially available products, or with drawings and designs shared so that teams have the ability to build their own. The relatively short FIRST history has created several small businesses providing these products, such as wheels, frames, various gearboxes and electronic components. .

An omni-drive is a drive system that allows a robot to move in three directions, often referred to as “3 degrees of freedom”.

Most common robotic drive systems allow a robot to move in two directions, or with 2 degrees of freedom. These directions are forward/backward (considered one direction), and rotation about a center axis. These directions are shown below in Figure 1.

An omni-drive system allows a robot to move in a third direction, side to side, without changing the orientation of the "front" of the robot. This third direction is shown in Figure 2.

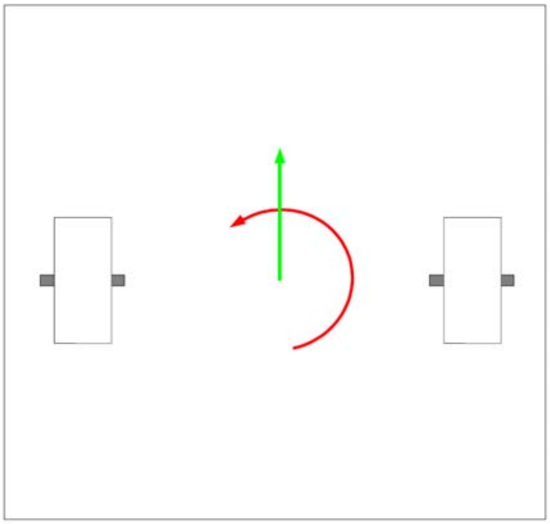


Figure 1 – 2 Degrees of Freedom

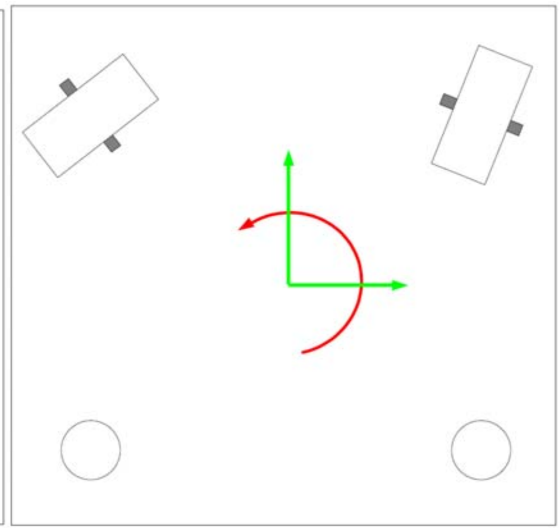


Figure 2 – 3 Degrees of Freedom

NOTE: It should be noted that "omni wheels", commonly available for FRC robots, are designed to give a wheel 3 degrees of freedom – they can move forward, rotate around a vertical center, as well as slide left / right. However, simply using these wheels in an in-line four or six-wheel drive system does not give a robot the third degree of freedom.

History – Origins of Omni-Drive Systems

1998 – Crab steering, FRC 47
1998 – OMNI wheels – FRC 67, 45
2002 – 3 Wheel Killough Drive, FRC 857
2003 – Ball Drive, FRC 45
2003 – Four Wheel Crab, FRC 111
2005 – Mecanum Style "Jester Drive", FRC 357
2008 – Three Wheel Crab, FRC 148
2010 – Commercially Available Omni-Drives (Team 221LLC, AndyMark)

There are several types of OMNI Drive systems. A few of the more common ones are described below.

Holonomic Drive (Mecanum)

A Holonomic Drive, often utilized with mecanum drive wheels, uses wheels with small rollers, with the rollers placed around the wheel and a slight angle inward. A picture of a mecanum wheel is shown in Figure 3.

In a mecanum dive, used by many teams in the 2010 FRC game "Breakaway", the robot moves by providing different levels of power in different rotation directions to each of the wheels. The wheels are arranged on the robot in a parallel orientation, with the rollers arranged to point inward to the center of the robot. By providing different directions of power to the wheels or to pairs of wheels, the force vectors either compliment or cancel each other, providing directional movement of the robot. In the Figures below, the small arrow indicate the direction of wheel rotation, the medium arrows indicate the direction of the force vectors, and the larger arrows (blue if printed in color) indicate the direction the robot will travel. This change in direction is accomplished by cancelling out different sets of force vectors, leaving the resultant vectors to determine the direction of travel. (See Figures 4 & 5 below).

Figure 3 – Mecanum Wheel

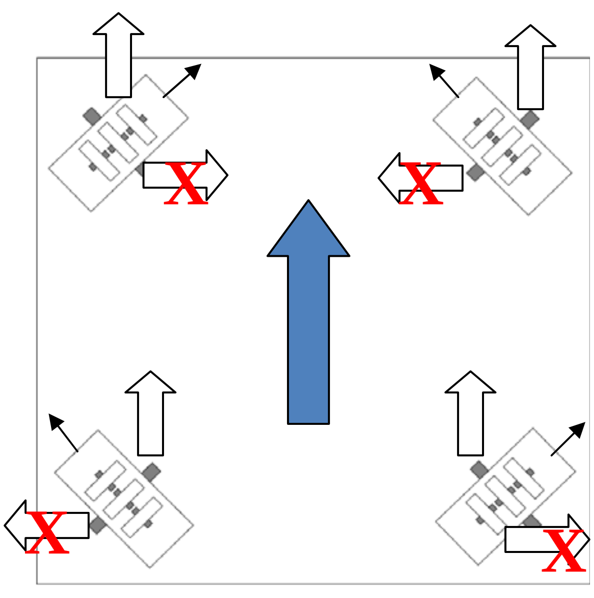


Figure 4 – Moving Forward

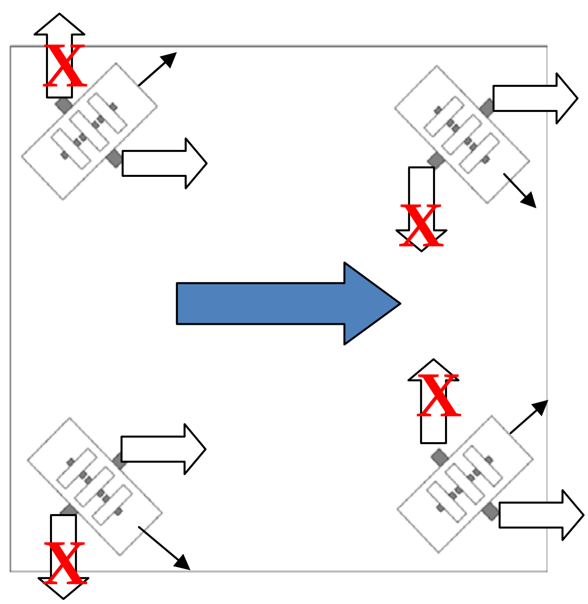


Figure 5 – Sliding to Right

Swerve Drive (Crab)

Swerve / Crab drives are a type of drive system where the wheels rotate to the left or the right, independent of the chassis itself rotating. These drives are called "swerve" or "crab" because of the way the robot looks as it moves around the field. A swerve drive allows the robot to move around the field as shown in Figures 6 and 7, without changing the forward orientation of the robot.

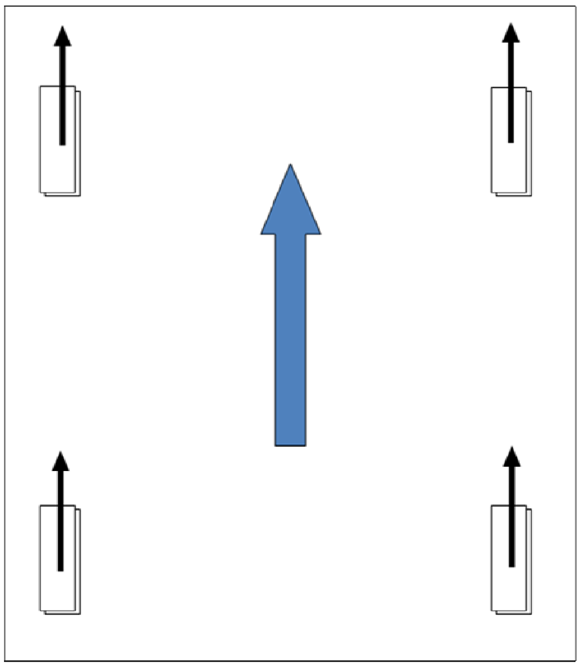


Figure 6 – Driving Forward

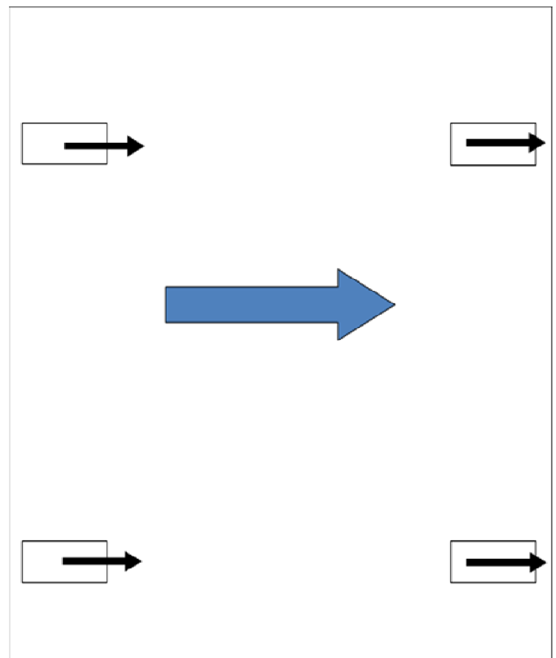


Figure 7 – Driving Right

Types of Swerve Drives

There are two basic styles of swerve drives, a distributed pod design and a co-axial design.

In a distributed pod design, each wheel pod has its own drive motor. These pods may also have their own rotation motor, or the rotation may be from remote, shared motors. A distributed pod design is the easier of the two systems to implement, but can be more limiting because the directional rotation is limited due to the need to provide wiring to the drive motors. A distributed pod style drive is shown in Figure 8. A sprocket on the top of the pod is used to provide the rotation of the unit.

In a co-axial drive design, the drive motors and rotation motors are both mounted remote to the wheels. This design requires co-axial shafts (a drive shaft within a drive shaft), with one shaft (typically the inner shaft) providing the driving power to the wheel, and the second shaft (typically the outer shaft) providing the wheel directional rotation. This design allows the wheels to rotate 360 degrees about their center axis. This design is more complex to design and build, due to the need to use co-axial shafts and bevel gears to provide the rotation power to the wheels. Figure 9 shows a co-axial module.

Figure 8 – Distributed Pod (Team 34)

Figure 9 – Co-Axial Pod (Team 118)

Figure 10 shows the prototype drive chassis used by Team 234. This chassis has distributed pods, with the front and rear wheel pairs orientation controlled by shared motor, away from the wheel pod.

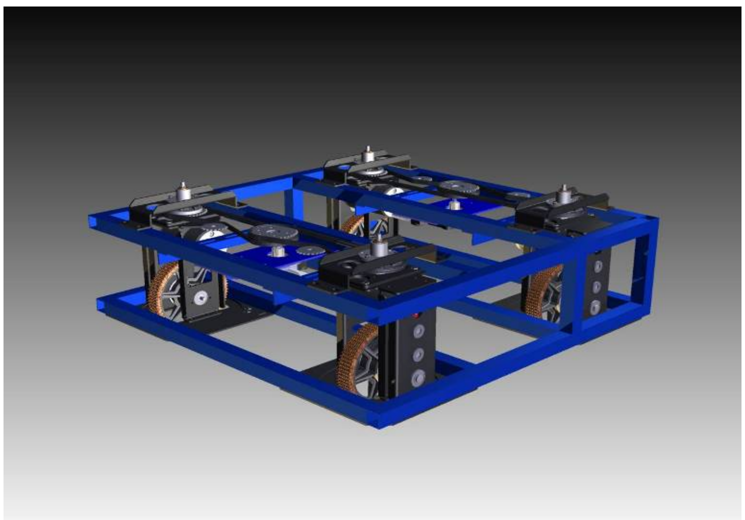


Figure 10 – Team 234 Prototype Chassis and Drive

Figure 11 shows a Team 118 robot with a co-axial drive. The co-axial wheel pods are chained together so that all wheels receive power from the same motor, and all change orientation together with another motor set.

Figure 11 - Team 118 Co-Axial Drive Chassis

Holonomic Drive Comparison

Below is a comparison of features of a holonomic drive compared to a swerve drive

Holonomic		**Swerve**
Easier to Build		Harder to Build
Lower Weight		Higher Weight
Relies on Wheel Slip to Move		Re-orients wheels to move
Low traction wheels required		Any traction wheel accommodated
Speed limited by wheels		Speed limited by gearing
Slow change of direction		Fast change of direction

Below is a comparison of a Distributed Swerve compared to a Co-Axial Swerve

Distributed		**Co-Axial**
Motor self contained in Pod		Motor outside pod
Limited orientation change due to wiring		Unlimited orientation change
Single speed gearing		Ability to shift
Power limited by single motor per wheel		Additional drive motors possible
Each pod requires a motor		Fewer motors for a minimum system
Easier to design / build		More difficult to design / build

SECTION II – CYBER BLUE IMPLEMENTATION

Introduction

This section describes the steps and the process used by Team 234 to develop a swerve drive system.

Step 1 – Evaluation

Our first step was to evaluate all of the swerve options for manufacturing requirements, design complexity, estimated cost, time to develop and overall technical difficulty. These were evaluated against a team goal to have a functional, competition ready system (modules, programming, controls and driving experience) for the 2010 FRC season.

Part of the evaluation included looking at several existing designs and implementations. Modules were borrowed from Team 118 (co-axial design) and Team 111 (distributed design). With the team's permission, these modules were examined as assembled, and then disassembled, inspected, measured, and re-assembled.

Decision 1 – Which Style

Based on the complexity of the designs and our manufacturing capability, the team determined that a distributed pod design (similar to 111) was the best decision for us.

Step 2 – Evaluate and Investigate New Information

As is common in many projects, there was new information available soon after making the design decision. The team learned that a small company, Team 221LLC, was in the process of developing and releasing a swerve drive module based on the Team 111 design. Team mentors contacted Team 221LLC and found that there were prototype units available for potential use.

This new information presented a new, major decision point for the team. Now, the team had the option to design and build their own modules, or to procure these prototype modules from Team221.

To make this decision, the team completed a make / buy evaluation.

Step 3 – Make / Buy Evaluation

Many businesses, especially engineering / design / manufacturing companies, are required to conduct make / buy decisions on a regular basis. These decisions are difficult and are often surrounded by a combination of facts, perceptions, emotion and even company philosophy. Often, a company's philosophy to make / buy will change over time.

As Cyber Blue looked at this decision, the team completed an evaluation matrix to compare the pros and cons of making or buying a swerve module. Key points from the discussion are noted below, and as discussed above, included some fact, some perception, some emotion, and some philosophy.

Make – Pros
- Fully understand the design and can take the product from design to finished part.
- Credibility and image – this would be our design
- Ease of assembly – could be part of the design process
- Easier to adapt and modify as we learned and developed
- Similar designs available to provide a baseline

Make – Cons
- Significant time required for the design phase
- Significant manufacturing time
- Requires manufacturing precision – would we need to outsource machining?
- Only a few would be involved in the actual design
- Longer time to a finished product – less programming time
- Longer time to a finished product – less driver practice time

Buy – Pros
- Fastest option to finished product
- Time for modifications to the overall drive system
- Time for programming
- Time for driver practice
- Identical to others in use (no disadvantage with unproven design)
- Potential to learn through assembly and inspection

Buy – Cons
- Would the units be "COTS" and legal for the 2010 season?
- Could we repair
- What will the cost be
- Possibly less learning by the team
- Availability of modules and spare parts
- Team Image
- Likely identical to many other teams (no advantage)

Decision 3 – Make or Buy

After significant discussion within the team, the decision was made to purchase the modules. In addition to the points addressed above, the team was able to work out an agreement with Team 221LLC to create the detailed build instructions, allowing the students to learn more about the design and assembly of the units. Some of the other factors of the final decision –

- The ultimate team objective was to have a working swerve drive system in time for the 2010 season. This option provided the highest likelihood of this occurring.
- This allowed the team to immediately begin to develop the drive as a full system (pods, chassis, motors, controls, electronics, programming, and driveability).
- This option provided the most time for programming and learning
- This option provided the most time for driver practice
- The team had the opportunity to learn from creating the assembly instructions
- This option allowed us to help other teams by providing early feedback to Team 221LLC on the design, assembly and functionality of the modules, prior to the 2010 season.

Step 4 – Obtain and Assemble Modules

After obtaining the 4 prototype modules, the team developed a process to create the assembly instructions. Our goal was to create an instruction set that would be clear and concise, and allow a team with limited technical expertise or capability to accurately and easily assemble the modules. To accomplish this we created four teams of 4 students and 1 mentor to work in isolation from each other to develop and then refine the documents.

For module 1, the first group of students and a mentor assembled one unit, taking pictures, documenting their steps, and creating simple CAD models of each assembly in the process. None of the members of the other three assembly teams were a part of this step

For module 2, another group of students and a mentor took the instructions already created, and then assembled a unit using only those instructions. As they worked, they made clarifications and updates to the instructions. This process was completed two more times, with each group using the latest update to the instructions and having no previous experience with the module assembly.

As we built, we also noted and documented any possible improvements to the units that could be incorporated for the final production design. One suggestion was an increase in the size of the mounting hole for the CIM motor, so that the drive gear could be installed before mounting the motor. This allowed for easier assembly, as well as a quicker repair capability if a motor would fail in competition.

For 2010, each module purchased included a copy of assembly instructions based on the work completed by the team.

Step 5 – Chassis Design

We determined that a basic chassis design would be our best option, and designed a simple rectangular cube, based on a 28” x 38” size. Since we were prototyping and knew there would likely be changes as we progressed, we selected 80/20 material to work with. 80/20 is easy to work with, can be assembled with nuts and machine screws, and could be easily modified as needed. We contacted 80/20, and after explaining the project we were working on, and our plan to share the process and results with the wider FIRST community, 80/20 agreed to donate the material needed to complete our chassis.

The primary requirements for the chassis were:

- 28” wide
- 38” long
- Top and bottom rails set for accurate mounting of the prototype modules (CRITICAL)
- Cross bracing dimensions set to accurate width dimensions for the prototype modules.

Chassis / Drive System Decisions

Figure 12 below will provide guidance for the following discussion on the chassis system.

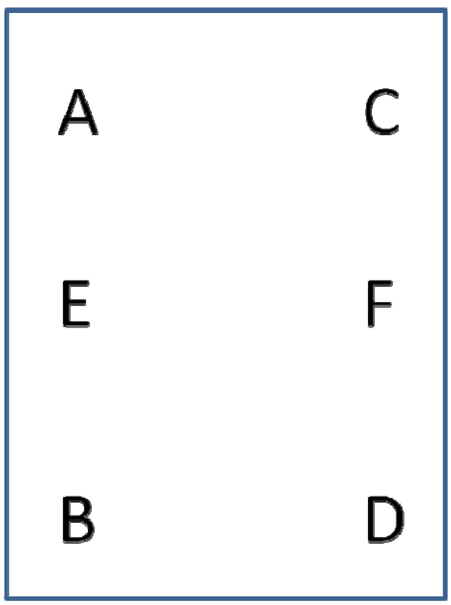


Figure 12 – Chassis Reference

Swerve pods were placed at the corners, noted as A, B, C and D. Globe motors were mounted at locations E and F to provide the directional control.

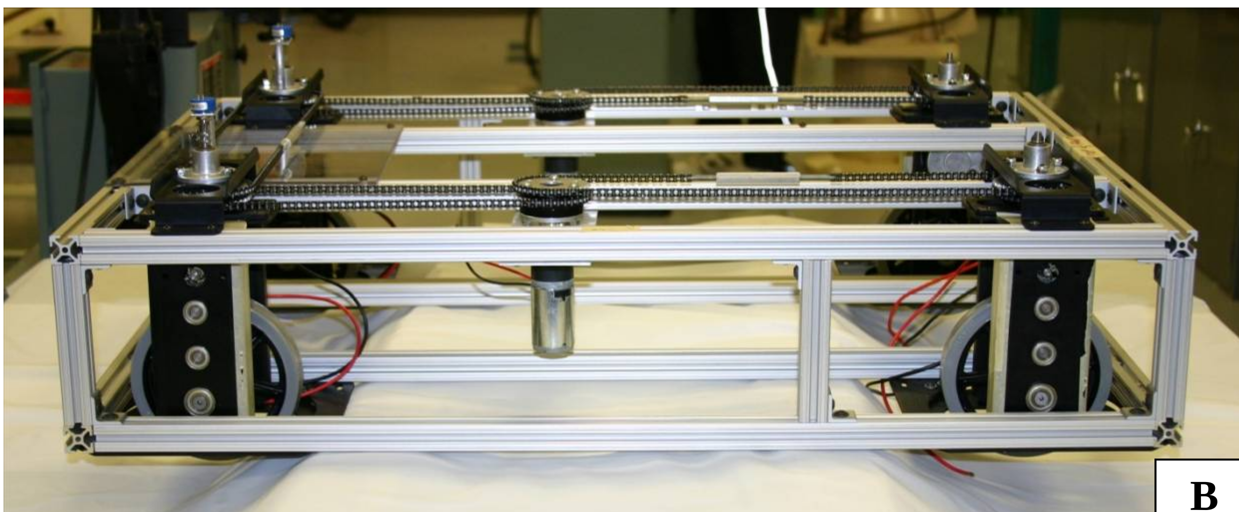
The left side (A B) pods were rotated by the motor at E and driven by chains. The right side (C D) pods were rotated by the motor at F.

Since we were just beginning our design, we also added two safety features to our system. We chose to add an additional set of chains to connect pods B and D, to be assured that all of the pods would move at the same rate and same direction. We also added a mechanical arm onto the sprockets at motor F, with hard point stops at + / - 100 degrees. This provided an extra precaution for over rotating the wheel pods and breaking something as we developed the programming for the drive.

To align the wheels, we used a piece of hard foam, 2" thick. We made precise cut-outs for the wheels, so that all four would be facing forward at 0 degrees. Once the wheels were held in place, the rotation chains were added from the globe motor sprockets. Adjustment plates on the swerve modules allowed for fine tuning of the alignment. Chain tensioners kept the chain in place.

For measuring the pod direction, the control system needs to know the angular position of the wheel pods. To measure this, we installed potentiometers on two of the wheel pods, one on each side.

Figure 13 below shows the complete chassis, with swerve pods and the globe rotation motors. For comparison, the wheel pod labeled as "B" in Figure 12 is located in the bottom right of this photo.



B

Figure 13 – Completed Chassis

Figures 14 to 17 add additional detail of the pods, chain and rotation motors.

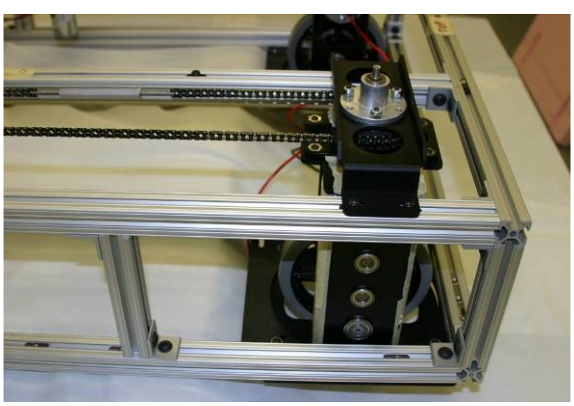


Figure 14 – Swerve Pod

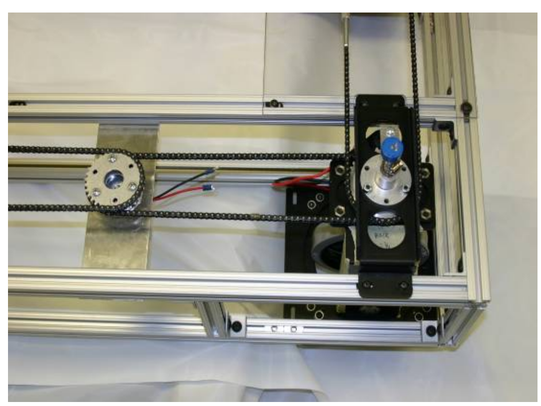


Figure 15 – Swerve Pod & Rotation Motor

Figure 16 – Rotation Motor and Chain Figure 17 – Globe Motor Mounted

Figure 18 shows an end view of the chassis system and details the locations used for electronics and the robot battery.

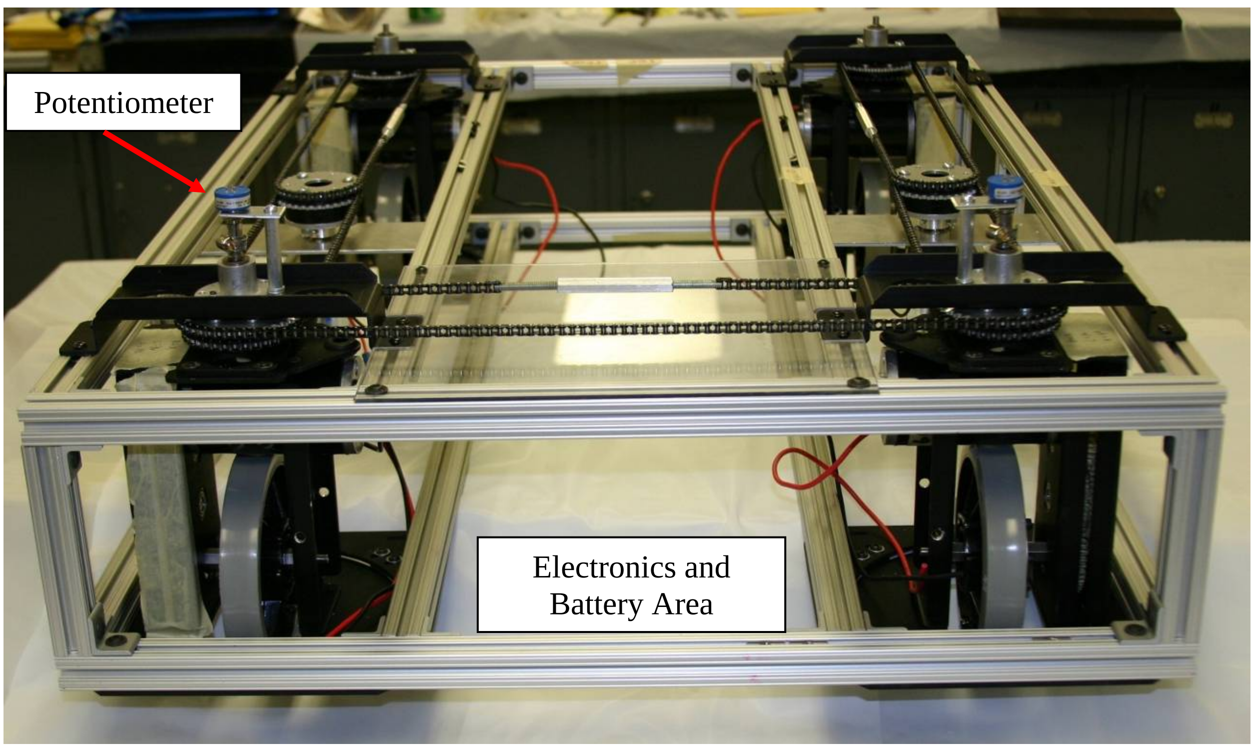


Figure 18 – View Showing Space For Electronics, Battery and Potentiometer Mounts

Step 6 – Electronics

The electronics team determined the required components to allow control of the drive motors, rotation motors and sensor inputs. These components were laid out off of the robot and then mounted onto an electronics board and added to the chassis. Once the system was installed, all of the components were wired and ready for testing.

Step 7 – Programming

The next step was to begin programming. The programming team had been working on code and doing simulations with the basics. Programming began work on the robot, with the first steps being to control the drive motors for forward and reverse.

Based on conversations with other teams, the first driver controls were joy sticks. One joy stick provided forward and reverse, the other provide control of the rotation motors.

After a short time, the team transitioned to a game pad module, still using the two joysticks for control, but in a handheld capability.

Several trial runs and check-outs were completed with the robot "on blocks". This allowed the team to get to a good level of control for the drive wheels and set the power levels (rotation speed) of the rotation motors. This included developing logic to rapidly move the pods to the desired angle from the joystick controller, but also the logic to slow down the movement as the pod approached the desired angle to avoid overshoot and chatter (jumping back and forth a few degrees while the control hunts for the exact degree orientation).

Logic was also added to disable the swerve capability if the two potentiometers gave different readings or if there was no signal. This was to assure that we would not over-rotate or break something due to not knowing the true direction of the pods.

Step 8 – Ground Test

The team then put the robot on the floor, and began to do some basic driving to learn the basics of controlling the robot on a playing field. A video of some of the early testing can be seen on the Cyber Blue website (www.cyberblue234.com) and on YouTube (Search for Cyber Blue Swerve or **http://www.youtube.com/watch?v=ax_dtCUUKVU.**

Results –

Cyber Blue believes the development and evaluation of the Swerve Drive system was a successful and valuable project for the team. First was an evaluation of a drive style, then a make / buy decision, then the team designed and built a chassis system. The final swerve system proved itself to be robust, solid and controllable during our fall evaluation period with several different student and mentor drivers.

We are continuing to work to improve and refine the system.

SECTION III – The 2010 Game

Drive Decision

When the 2010 game was announced, Cyber Blue felt it had another drive system option with the Swerve. After our game evaluation and brainstorming, the team decided that the mobility offered by the swerve system was important to our strategy and then began the process of incorporating and adapting what we had learned into the 2010 robot design.

Changes 2009 Development to 2010 Game

We took many of the lessons learned (positive and negative) in the 2009 project into our 2010 robot design. A few of the differences between the two systems are below.

Mechanical Changes to 2010

- The Swerve Pods were new, production (COTS) parts from Team 221LLC
- The wheels were changed to traction wheels.
- The front wheel pods were linked together for directional orientation control.
- The rear wheel pods were linked together for directional orientation control.
- Window motors were used for directional orientation (globe motors not in KOP).
- Potentiometers were moved from the top of the wheel pod to being driven off of the rotation motors.
- To allow space for the kicking system, the modules were closer together (front to back).

Control Changes to 2010

Single Stick Tank
The game pad controller incorporated a “single stick tank” capability.
By using on the right joystick, the robot would drive forward and backward. If the driver pushed the stick slightly to the left, the control would provide more power to the right side drive motors, causing the robot to turn to the left. Similar movement of the stick to the right caused the robot to turn right. This simulated regular “tank” drive.

Swerve Control
To drive with Swerve control, the right joy stick works as above, for forward and reverse. The left side joy stick then provides the input for the directional orientation of the pods – left and right. Moving the stick to the left turns the wheel pods to the left, moving to the right causes the pods to move to the right. Note that “left” and “right” are relative to what is considered to be the front of the robot, and so from the driver’s perspective could be reversed depending on which way the robot is facing.

Car Drive
To attain greater control for obtaining a ball and scoring, a car drive option was added. This allowed the driver to change the directional orientation of the robot with the front or

rear wheels, letting the robot move like a car to make turns. This option was enabled with the push buttons on the front of the game pad.

Figure 19 – Inventor Rendering of Chassis with Drive Modules

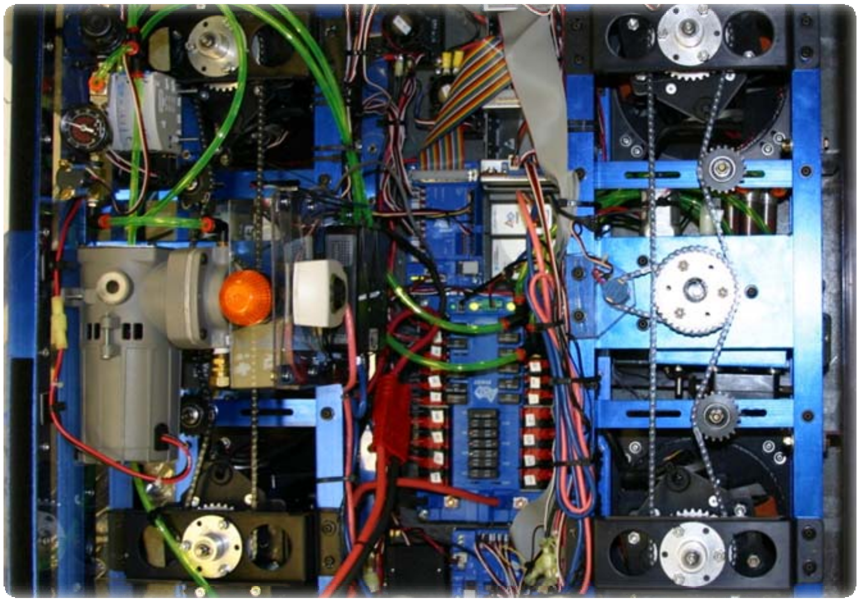


Figure 20 – Top View of Finished Robot (Actual Photo)

Lessons - Important Conclusions

1. Make a tool or template to align the modules as the system is being assembled.

2, Dimensions and alignment of the wheel pods is critical. Misalignment causes friction, making it difficult to rotate the pods. This can lead to motor overheating and cut-out.

3. Rotation motors can easily overheat, due to the friction in the system for rotation. Limit the rotation of the pods when the robot is stationary, the traction wheels and carpet have a high co-efficient of friction. The motors have thermal breaks in them, and when they cut out they need several minutes to cool.

4. Plan for things to go wrong, and build in safe guards and devices as you develop. Some examples were chaining all wheels together for rotation, and also having a mechanical stop in place.

5. It is never too early to start a project. Be cautious about trying to develop a new system (such as a new drive) while you are in the crunch of the 6 week build season.

6. Talk to other teams. Learn what they have done. Adjust and adapt to your objectives.

7. Purchase is often an option, but not the only option. Make this decision based on your team capability, goals, philosophy and funding.

8. Get something on the ground and driving as soon as possible. Intermix driving and programming. Work together and learn together to make the system better.

9. Never settle for “good enough”.

Next Steps

As we enter the summer and fall of 2010, we intend to continue to work and expand our knowledge, capability and understanding of this drive system. Some of the potential activities are:

1. Options for weight reduction
2. Addition of access points to tighten nuts and machine screws.
3. Creation of a solid mounting for the potentiometers.
4. Placement of individual rotation motors on each pod.
5. Experimenting with pneumatic actuation for pod rotation.

SECTION IV – Sources

The following teams and companies were significant sources of information and / or materials for this project. Their input and support is greatly appreciated.

Team 118, Robonauts – For information and the use of a co-axial swerve module in our evaluation, and for their presentation at the 2009 FIRST Championship Forums.

Team 111, WildStang – For information, programming support and the use of a swerve module in our evaluation, and for being the inspiration behind "WildSwerve".

Team 221LLC (Anthony Lapp) – For allowing us to procure prototype hardware and to create the WildSwerve assembly instructions. Also for letting us having input into the final design.

Andy Baker – For providing much of the information included in the "History" section.

80/20 (Don Wood and Doug Wood) – For supporting us with materials and support in creating the prototype swerve chassis used throughout the fall. The flexibility of 80/20 material allowed us to 'rebuild' the robot into our prototype 2010 Competition Chassis.

Other Teams – Many other teams have worked to create omni drives over the past 10 years. We are very appreciative of all of the work teams have done to contribute to the current level of omni-directional drives for FIRST robots.