A GUIDE TO OCCRA 2016

Robot Design - Getting Started By Thomas Rice

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(Reading done in The Robot Builder's Bonanza by Gordon McComb.)

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Figure 1: Six different types of FIRST robots.

Section 1: Introduction

Suggested Reading – Introduction and Chapter 1

This manual is not being written to give you all the answers. It is a manual to help your team or your class get started. Therefore, it is intentionally open-ended. It is, however, designed to give you some of the basic building blocks of robot design and ample room for design creativity. Because of the time restraints and because I don't believe in reinventing the wheel, I'm using the second edition of The Robot Builder's Bonanza book by Gordon McComb (ISBN 0-07-136296-7, McGraw-Hill, Cost: $24.95) as a reference and to give the bulk of the material throughout the manual. This manual is primarily aimed at teams competing in the Oakland County Competitive Robotics Association, but can be used for teams competing in the FIRST Competition, the Society of Manufacturing Engineers Student Robotics Competition or any other robotics competition. Robotics is an exiting and developing field. Catch the wave and get involved. I hope you find this information useful and good luck in the up coming season in the Oakland County Competitive Robotics Association's Robotics Competition.

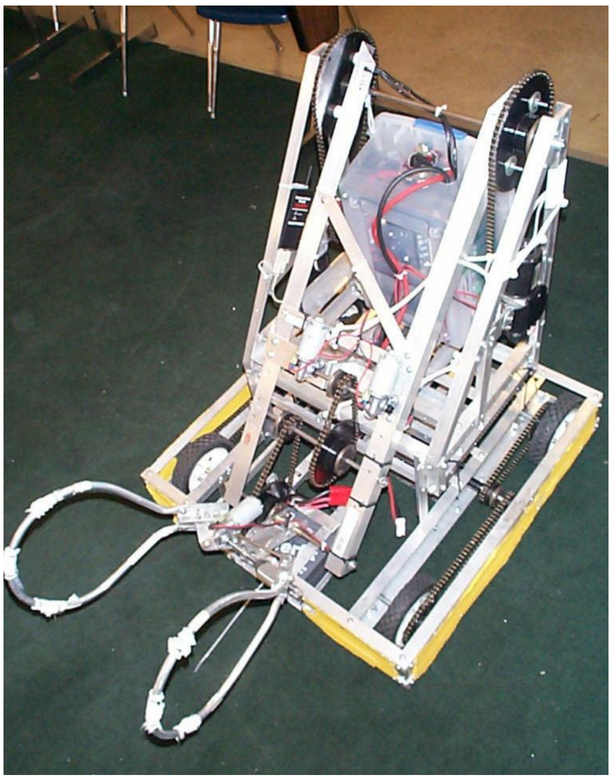

Figure 2: The 2000 OCCRA Oakland County Champion Robot.

Section 2: Design Process:

Suggested Reading - Chapter and Appendix A & C

There are a lot of books addressing the design process; do some research. In time you will develop one that fits the needs and special characteristics of your team. I'm going to discuss the process that has been successful for our team. It's a process that is meant to be meaningful to students and constantly improving through lessons learned during each competition season. Below are listed the steps of that design process. Use them as a general template to get started.

1. Define the design parameters. Review the rules and field characteristics of the game. Examine the kit of parts and figure out what each part can be used for. Do a walk through of a few matches using people as robots to examine different strategies for maximizing points or defending; clarifying how the game is played.

2. Discuss the pros and cons of having a defensive robot design, offensive robot design or some combination of the two.

3. Research the different parts of a robot; what they do, how they fit together and different ways they're constructed. (Refer to books like the Robot Builder's Bonanza.

4. Brainstorm for robot design ideas. I find it most effective if each individual is required to sketch at least one design idea. This can be either one part of the robot or the whole robot design. This allows even the most timid individuals to be heard.

5. Justify the design ideas. Once all individuals have turned in their design, have each come up and explain their design to the group. After the different designs have been explained and discussed, post them on a bulletin board for further examination and discussion.

6. Vote on the design ideas to narrow the field. Get it down to a manageable number of good, solid ideas.

7. Prototype the best design ideas in a medium like Legos to further explore how well they're going to work.

8. Vote on the prototypes (The votes should be predicated on technical justification and not on who's most popular, etc..) to narrow it down to the final design.

9. Split up into subassembly (These are the different parts of the robot like the gripper, base and drive train, arm or lift, shoulder or turret, etc..) groups to start robot construction.

10. Set up a project management schedule or time line to coordinate the implementation of robot construction.

11. Work up a cost estimate for additional materials.

12. Buy or secure needed materials.

13. Build robot subassemblies.

14. Test each subassembly as it's finished for proper operation.

15. If there are problems with a subassembly, repair it or repeat the design process to come up with a better one to replace it.

16. Put the subassemblies together to complete the robot.

17. Test the finished Robot.

18. If there are problems, repair them.

19. Practice as many hours as possible with robot on the playing field.

20. If time allows redesign weak points or problems.

Figure 3: The design process is a team effort and where successful robot design begins.

Section 3: 10 Simple Rules for a Winning Team:

Suggested Reading - None

Our team developed a creed or set of rules we believed profiled a winning team the first year we competed. These rules are based on what we believed would make us winners as well as winning characteristics observed of winning teams we competed against. These rules have been added to and slightly modified as we learned more through each year of competition. These rules govern the design process of building a successful robot and the design process of building a successful team.

1. **Strategy drives design.** (Know the goal of the game and the rules. Formulate a strategy based on that knowledge and design a robot that fulfills the needs of your strategy.)

2. **Simplicity usually wins.** (Don't over engineer your robot. Find a simple and efficient way to implement your design parameters that will minimize repair problems during competition but maximize strength, agility and speed on the field.)

3. **Responsibilities are organized and distributed equally.** ("There is no "**I**" in team." If jobs are equally shared the work load of each

individual decreases while the effectiveness of the team increases. Also, cross training is important. Cross training allows team members to cover for other team members in case of absence or when an unexpected problem arises which pulls someone off their assigned responsibility.)

4. **If the Time Line isn't being met, simplify and redesign.** (Don't get stuck on an idea or design that can't be implemented in the competition time frame. Remain flexible to new ideas that allow you to still reach design goals. Even if it means ending up with a robot that doesn't fit the original vision but is simpler, more practical and will do the job. Go for it. You should not have to work all night to finish the robot the day before the competition. The driving team and coaches need time to practice with the robot. Otherwise, it's like putting a hammer in the hands of a baby and expecting the baby to build a house. There is no way your team can be at 100% for competition day under these circumstances. Constantly reassess whether you are meeting the deadlines set by your project management schedule or project time line. If you're falling behind examine and implement solutions to get your team back on track. If there are team members blocking that from taking place, it is the responsibility of the team leader to have those members sit in the "time out chairs" so others can get the project back on track.)

5. **Once designed and built, the robot is a tool. Use it to its maximum effectiveness; no regrets.** (Once the robot is built don't have "sour grapes". If it didn't turn out exactly the way you wanted it, accept it. The team should always have a positive attitude toward the results of their efforts. Take pride in your accomplishments. If minor modifications can be done to improve the machine's performance, do it in a positive way. Nobody likes to hear, "I told you so" or "We should have done it my way". It's time to take what you have, hone your skills with it on the practice field and be the best that you can be. A mediocre machine with a well practiced drive team and sound strategies will almost always beat out a finely designed machine with a drive team that didn't have enough time to practice and develop their strategies.)

6. **Minimum input for maximum output.** (Always follow the ideals of lean manufacturing. Find the simplest, least expensive and most efficient

way to get the results you want. Anything less is wasted time, effort and money.)

7. **Be ethical, live the positive image and you'll get positive returns.** (Be good winners, be good losers, help other teams when they need it, treat others with respect and endeavor to be positive. It will come back to you a thousand fold.)

8. **Keep what's best, throw out the rest.** (Always follow the ideals of quality management. I don't think this needs a lot of explanation. You learn a lot from experimenting and applying new ideas your team comes up with and the ideas in use by other teams. Implement and integrate the ideas you find work and complement your team and disregard the rest. Make sure your team is living up to the quality benchmarks or it has set for itself.)

9. **Marketing your accomplishments yields financial returns.** (Let the community know what your team is doing. This can be through newspaper articles, a team news letter or a team web-site. It may foster a parent booster group, a corporate sponsor, funding support from local businesses or help capture funds for scholarships.)

10. **The responsibility for robot actions on the field are equally shared by coaches, drivers and pit crew.** (When we choose drivers we run them through a rigorous testing process. Some characteristics we look for are good eye-hand coordination, ability to listen, ability to communicate effectively, receptiveness to constructive suggestions, ability to think and react fast and coolness during competitive matches in front of large audiences. Similarly, a set of criteria needs to be in place for deciding who should coach, be on the pit crew to fix the robot as well as any other jobs on the team. How well this process is orchestrated and executed will determine how successful the team will be.)

Section 4: Necessary Tools and Supplies

Suggested Reading - Chapters 3, 4 & 5 and Appendix B & E

It's important to have the right tools to build the robot and to repair the robot. Also, it's important to have them organized, labeled for identification purposes

and be able to easily transport them to competition. In this competition there can be no precision made parts. That limits the tools to some pretty basic types. In Chapter 3 the author lists basic, optional and electronic tools. He's done a fairly good job, but I feel it necessary to add to the list these additional tools. When you're buying tools shop around and get the best deal.

Figure 4: Basic tools and fasteners are all you need to assemble your robot.

Basic Tools

1. 2 or 3 wireless electric drill/screw drivers with assorted bits
2. Set of hex or Allen wrenches both Metric and English
3. Set of sockets with a ratchet handle both Metric and English
4. Pop rivet gun with an assortment of pop rivets
5. Hot glue gun with some hot glue sticks
6. Assorted punches and Chisels
7. 2 lb. sledge hammer
8. Channel lock pliers
9. Slip-joint pliers

10. PVC pipe cutter
11. Hand reamer
12. Duct tape
13. Vise
14. Rolling tool box to transport tools to competition (Kmart or Home Depot)

Optional Tools

1. Wireless electric hand grinder with assorted bits
2. Band saw with blades for cutting metal and wood
3. Light duty pedestal grinder
4. Wireless electric saber saw with assorted blades for wood and metal
5. Small anvil
6. Cart to carry robot on and off of field

Electronic Tools

1. Diagonal wire cutters
2. Needle nose plies
3. Crimping tools for light and heavy gauge wire
4. Assortment of solderless connectors
5. Wire strippers
6. Heat gun with heat shrink tubing
7. Tie wraps or cable ties
8. Electrical tape
9. Desoldering braid
10. Heavy duty soldering gun
11. Battery Charger

Hardware supplies can be bought at any hardware store or stores like Home Depot, Kmart, Meijer's, Sam's Club, etc. Plan ahead so you don't end up with a lot of unneeded surplus and expense. Also, develop a plan for supplies and hardware needed to repair your robot at competition. These materials should be organized so they are easy to find and access at a moment's notice and complete enough to anticipate any needed repair. Our team takes two rolling toolboxes to competition. One is used for tools while the other is used for parts. Make sure you check the official OCCRA tool list in the appendix of the kit part of this manual.

Safety: *Safety is a must when building robots. It is a good idea to have your robot team watch a shop safety video and take a safety test to ensure safety competence. Safety is an attitude that must be practiced on a daily basis to minimize accidents and keep everybody safe. Safety glasses should always be worn in the shop area and in the pit area during competition. Long hair and loose clothing should always be tucked in when working around power tools or robots. Jewelry should be removed when working with electricity. Be proactive when it comes to safety.*

Figure 5: Safety Glasses should always be worn in the pit area.

Section 5: Building a Robot Base

Suggested Reading - Chapters 8, 9, 10, 21 & 22

Figure 6: Make sure in initial base layout that you choose the best materials and select the correct dimensions.

The base is the foundation of your robot. Without a strong foundation you run the risk of disaster on the playing field. Its design should anticipate the addition of the drive train, turret and lift system. So attaching a metal frame to it to accommodate the addition of these devices might be a good idea (Check out page 333 and the frame on the robot being built in Chapter 21.). When sizing the base you should take into account the addition of protective bumpers or wheels so as not to exceed game rule limits for the outside dimensions. Also, it is important to remember that the controller box is going to take up a lot of space. It needs to be placed on the base in a strategic way so it is easily accessible for wiring and repair, anchored down securely, protected from injury during competition matches and doesn't clash with any other devices attached to the base or frame (if you have one). It is very important to remember that all the electrical devices on the robot will have wires running to the control box. **Make it accessible!!!!!!**

Figure 7: Here is a FIRST robot where the control system and wiring are well protected and still accessible.

Don't limit yourself to the three chapters that I gave for suggested reading. There are good pictures of built frames with attached drive trains, wheels, etc. in other chapters scattered throughout the book. You should browse a bit. See if this information doesn't help guide your design and get you started on the building process. Last but not least, keep the center of gravity (majority of the

weight) of the robot as low to the ground as possible. It will make the robot stable and hard to tip over.

Section 6: Voltage, Current, Wires and Batteries

Suggested Reading - Chapter 15 and Appendix E

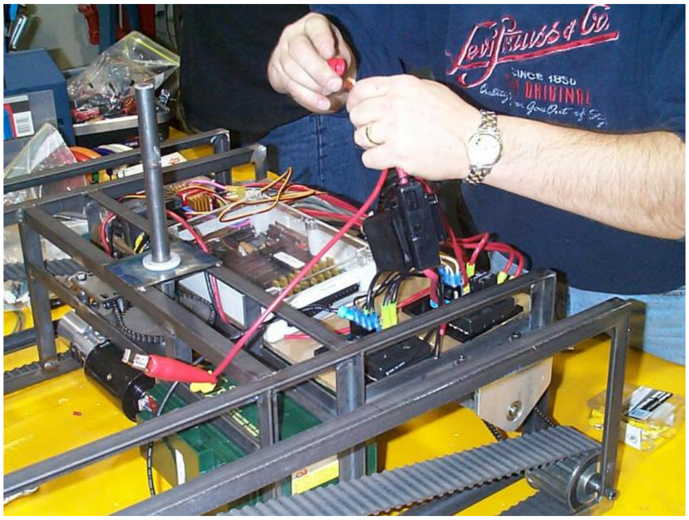

Figure 8: Robot being wired for action.

Voltage is the potential difference between negative and positive in an electrical circuit. It's sort of like a pressure that moves the electrons through the wires. This movement of electrons is called current which does the work. Current is the life giving blood of your robot, the wires are the arteries and veins and the battery which provides the voltage is sort of like its heart. The worse thing that can happen on the playing field is that your robot has a heart attack because the pit crew didn't give it its annual check-up in the pit between matches. The battery needs to be kept fully charged in order to keep the muscles of the robot, its motors, running their strongest. Using a digital multimeter set to DC (direct current) volts, measure the voltage of a couple of fully charged battery. Take the average of the two measurements and use that as your reference for fully charged. Then take some voltage reading of the batteries when the robot starts showing signs of decreased performance and use the average of those measurements to determine when batteries need charging. Not a foolproof method, but it seems to work most of the time.

Smoke is bad. Hit the main circuit breaker if it doesn't blow on its own, disconnect the battery and troubleshoot the system for the problem. Repair before reactivating the system. Smoke occurs when excessive current is being drawn by an electrical device. It will usually be hot and can burn you so be careful when you're troubleshooting.

Chapter 15 does a great job of explaining batteries. Wear safety glasses when charging and changing them. Make sure the battery holder is in an accessible place for easy changing, but protect the battery cables. If they come off during a match you're dead in the water. (**Always wear safety glasses in the pit area!**)

Section 7: Motor Control, Mechanical Advantage and Robot Base Motion

Suggested Reading - Chapters 16, 17, 18, 19 & 20

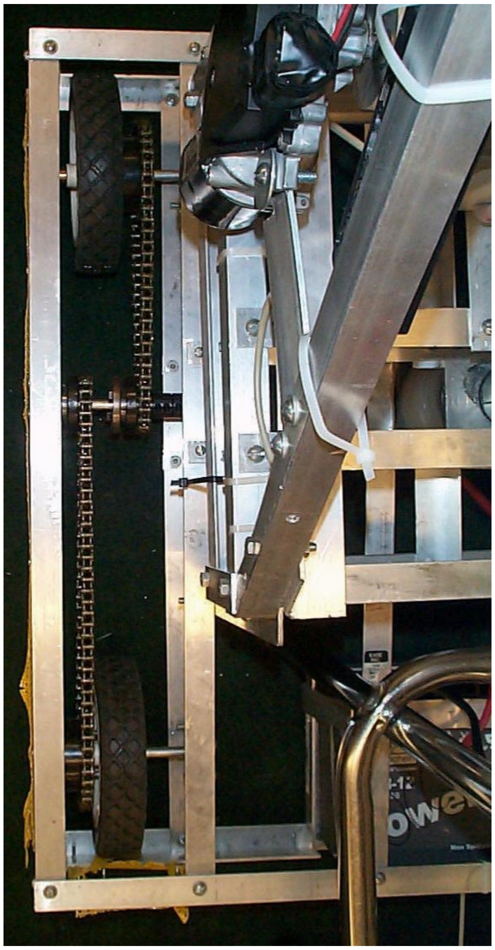

Figure 9: This is one way of configuring a four-wheel drive robot base.

Robot base motion is produced by wheels or tracks making contact with the floor and being driven by motors through gears, chains and sprockets or belts and pulleys. Regardless of what drive system you use, the goal is to find the fastest

most powerful design that meets the needs of the strategy of the game. This means selecting the right motor and matching it to the right drive system with the right mechanical advantage to provide the best strategic performance. It is also important to remember that the current draw of a motor increases proportionately to the load on the motor shaft. Getting the base to move and turn while pushing another robot will most likely produce the greatest load any motor on the robot will have to handle. So, I'm going to make the suggestion that you choose the most powerful motors that can still provide the necessary speed to drive the base. You will have to determine which motors those are by methods like the one explained on pages 240 - 242 for measuring the torque of a motor or the amount of force a motor exerts on its load.
You can also change the mechanical advantage or speed of the base by adjusting the size of the gear ratio between the driver and the driven. The driver is the gear, sprocket or pulley that is attached to the motor shaft. The driven is the gear, sprocket or pulley being turned by the driver. If the driver is smaller than the driven, you sacrifice speed for mechanical advantage (torque or power). If the driven is smaller than the driver, than you sacrifice mechanical advantage for speed. You have to determine which ratio between driver and driven is most advantageous for your application.

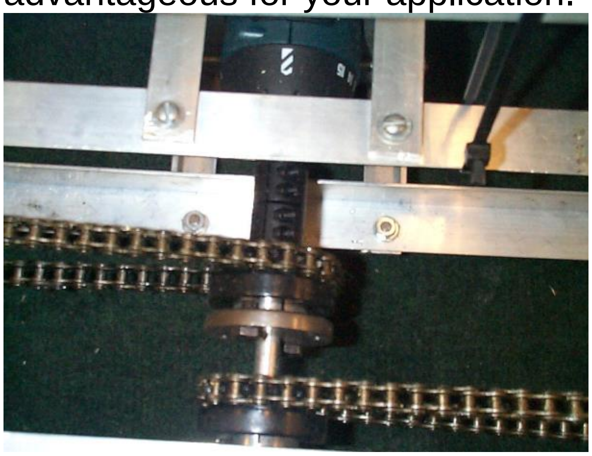

Figure 10: Don't side load motors. Make sure you support motor shafts on both ends with bearing surfaces.

Mounting the motor and aligning the drive system is important for minimizing load on the motor. Make sure that the base motor mounts fasten the motors securely to the base. On page 120 are examples of fabricated motor clamps. This is to give you an idea of how to do it. You may come up with a better design. You should be creative. You also have to decide whether you're going to use a two-wheel, four- wheel or track drive. Four wheel and track drives

require a more complex drive design, but are the most powerful (See pages 358 & 365). Two-wheel drive is the most simple and considered to be the fastest and most agile if built right (See page 333).

The base turns by the drive motors rotating in opposite directions. It goes forward and backwards by the motors rotating in the same direction. Turning and direction change is done through the speed controllers in the controller box. It is important when hooking the motor up to the speed controllers to have proper polarity. Implement a wire color scheme to make it easy to unhook and hook up motors correctly. Red traditionally stands for positive and black for negative. Label your wires to allow easy identification of wire runs. This becomes extremely important in troubleshooting robot problems.

Take from the chapters those things you find useful and skip over the rest. There is a lot of information to cover. Again, remember that the base is the foundation of you robot. A good base with a good base drive system will do great in competition.

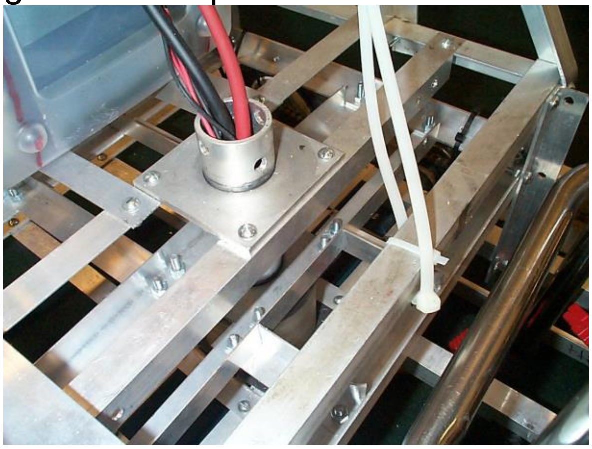

Figure 11: Make sure you choose a Strong material to build the robot's base. Also, frame the base and other parts of the robot using both perpendicular and diagonal cross-supports for strength.

Section 8: Building an Arm or Lift Mechanism

Suggested Reading - Chapter 24, 25 & 26

Figure 11: Here is an example of a lead screw mechanism being used for a lift system.

A competitive robot almost always has to lift some object like a ball, box or inner tube and place on a goal of some sort. Whatever the task it has to perform during the game will determine the design of the arm or lift system, whether you put a turret on it, if you use a wrist mechanism and what type of gripper you use. To hold to the rule of simplicity you should limit the number of axis on your robot to those necessary to play the game. An axis is any point on your robot around which a mechanism revolves or pivots. Each axis requires at least one motor to drive it. Therefore, the more axis you have, the more required motors and the greater the power drain on your battery.

The chapters to be read give good examples of some different kinds of arms and how to power them. But you're going to have to expand on these designs and make your arms and lift systems stronger by building better supported frames. You might even want to go with dual mounted drive motors on each side of the arm or lift. This would make the arm or lift more powerful and faster. Make sure you align all drive systems to minimize excess load.

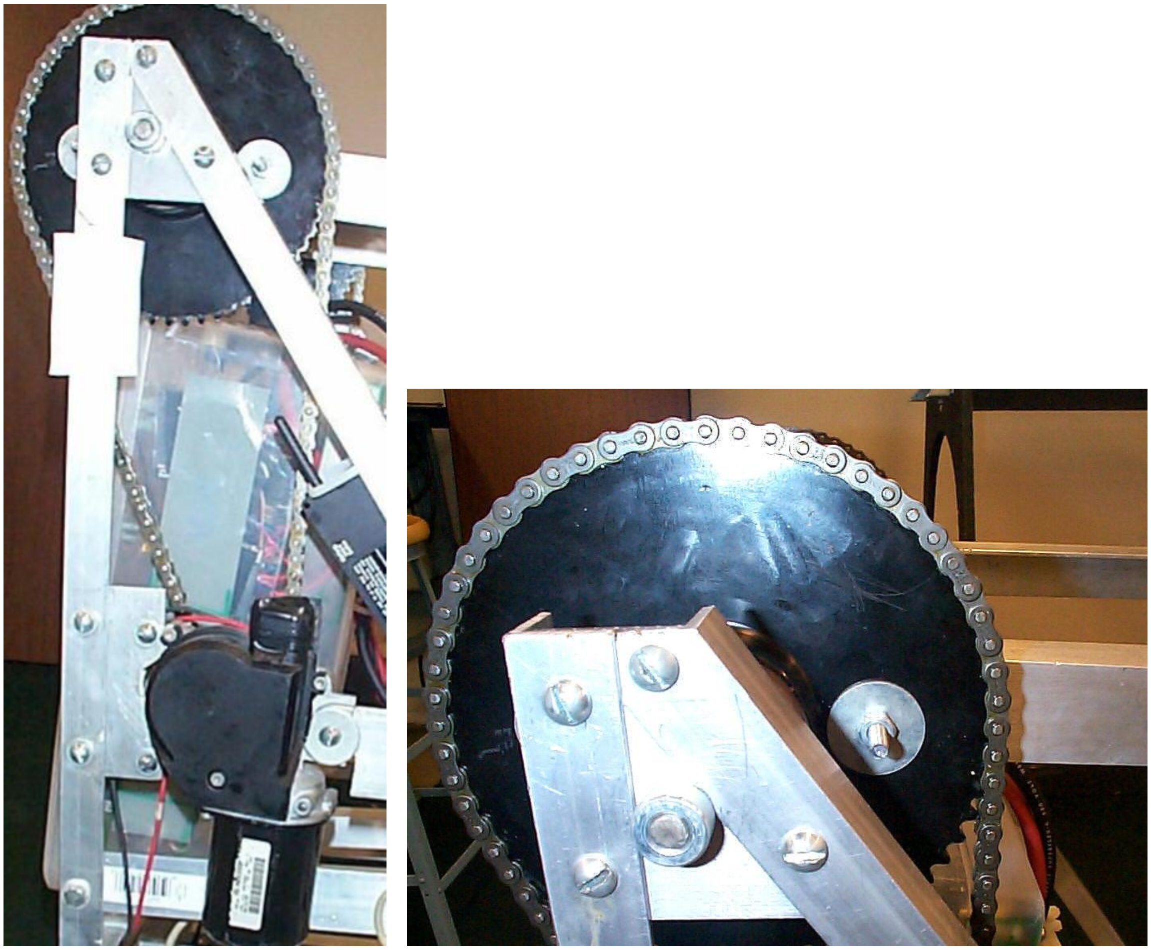

Figure 12: Here is an example of a chain and sprocket mechanism being used for a lift system. Notice in the picture on the left that solid framing has been employed to minimize chance lift system failure and maximize lift system support.

Section 9: Building a Wrist Mechanism

Suggested Reading - Chapter 27

A wrist system may be the least important element to be considered on a competitive robot. It all depends on the game. There are three kinds of wrist movement pitch, yaw and rotational. Pitch is the up and down movement. Yaw is the side to side movement. And, rotational is the pivoting of the wrist around its center axis (See page 416). I believe the only wrist movements to be considered are pitch and rotation. The whole point of the base, arm and wrist movement is to deliver the end-of-arm tooling payload to a desired location. If adding a wrist movement gives your robot a decided advantage in accomplishing

the game task, then add it. But remember, it will add more weight to the end of the robot arm making it more unstable or top heavy.

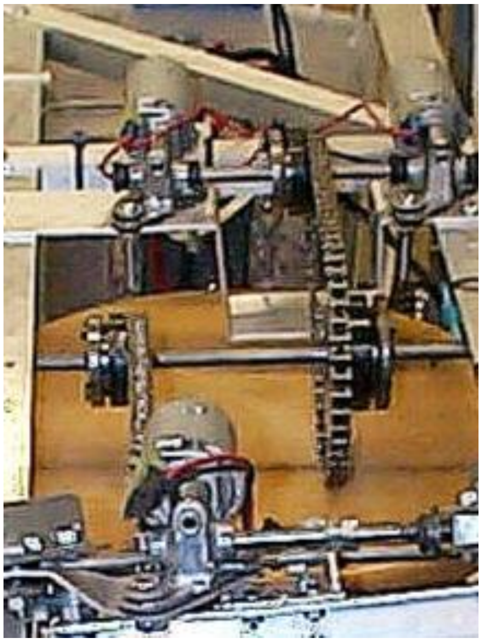

Figure 13: Here students added a pitch wrist movement to their robot using a compound chain and sprocket system.

Section 10: Building End-of-Arm Tooling

Review - Chapter 27

This part of the competitive robot, unlike the wrist, is possibly the most important. It is the part that delivers the points to the goal. Its movement should be smooth, simple and fast. Using a center pull system with a pulley and cable system like the one on page 413, allows the drive motor to be mounted somewhere down the arm helping to keep the center of gravity low.   A worm gear drive (See page 411), a lead screw drive or rack and pinion drive provide greater power when grabbing. The finger design should be such that it can grab the ball, box or what ever it may be and deliver it without getting hung up on any part of the goal. Sometimes it is better if the end-of-arm tooling can hold more than one object. If that's the case, a compartment that can be loaded and emptied should be designed. This could be something like two belts on motors sucking the objects into the containing system and then spitting them back out to deliver them to the

goal for game points. What ever you decide spend some quality time on this part of the robot.

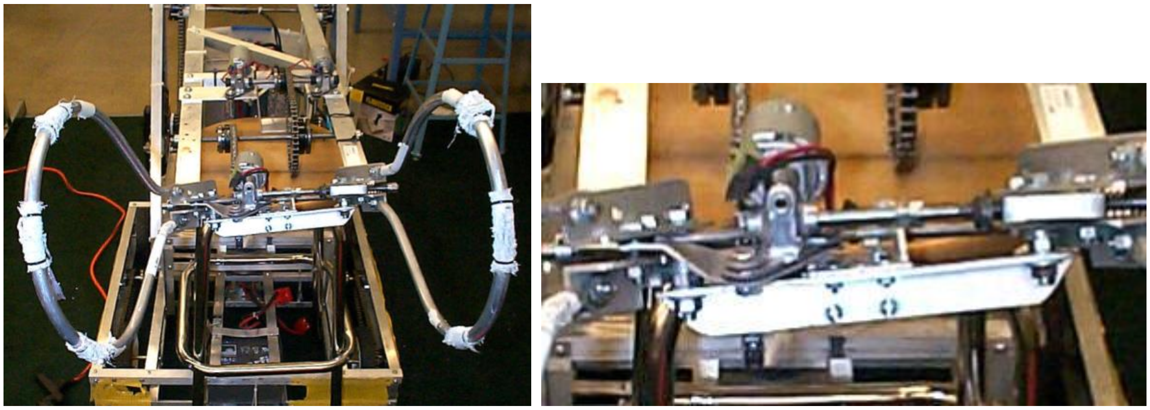

Figure 14: End-of-arm tooling should be simple yet adequate for the task. This unit was designed to pick up balls. It used a combination of levers and linkages with a lead-screw mechanism to provide a way to open and close it.

Section 11: The Controller and System Integration

Suggested Reading - Chapters 31 and 34

Even though the chapters in the book don’t follow the controller set up for this competition very closely, I think they’re still valuable read. There will be another handout that will talk about specific ways to hook the motors up to the controller, explain how the controller works and how best to utilize the system. Use that handout for this section. Make sure all connections are tight before you go out to play a match. Keep your joystick/control board in a safe place in between matches. Check indicator lights on controller, speed controllers and spikes for proper operation. Make sure you have extra fuses for the controller in case one or more blow out.

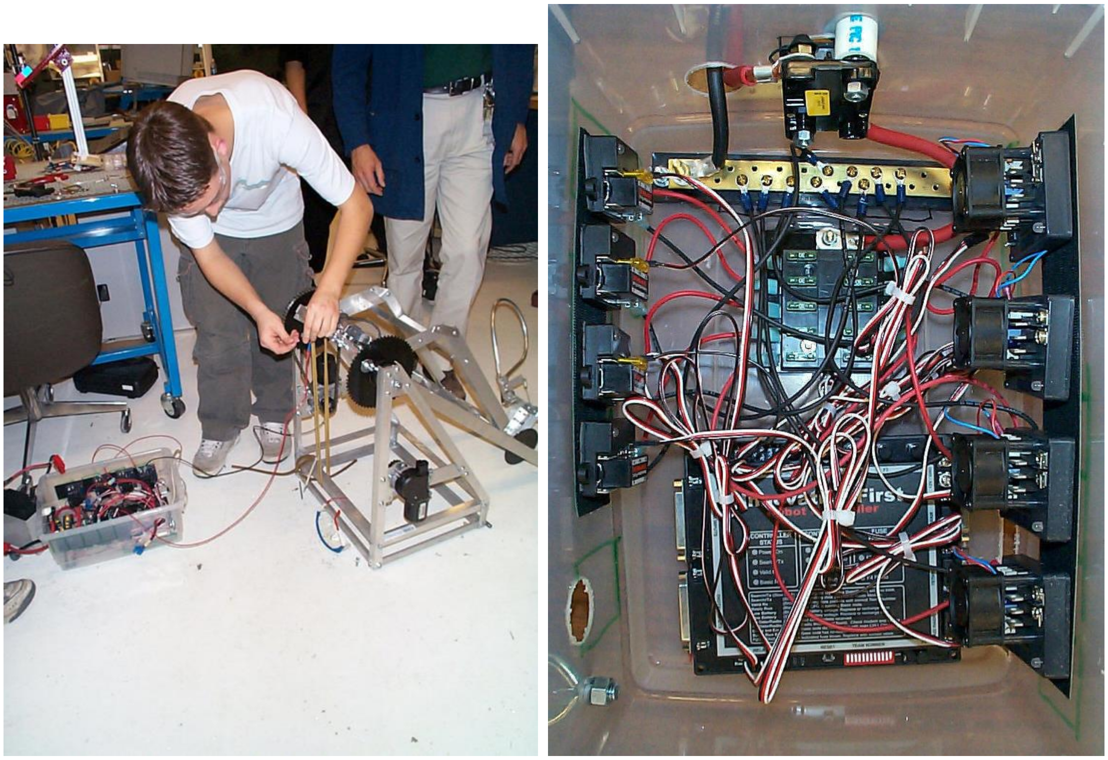

Figure 14: Make sure each subassembly is tested before integrating it with other subassemblies.   Find a place on the robot that is well protected when mounting the controller.

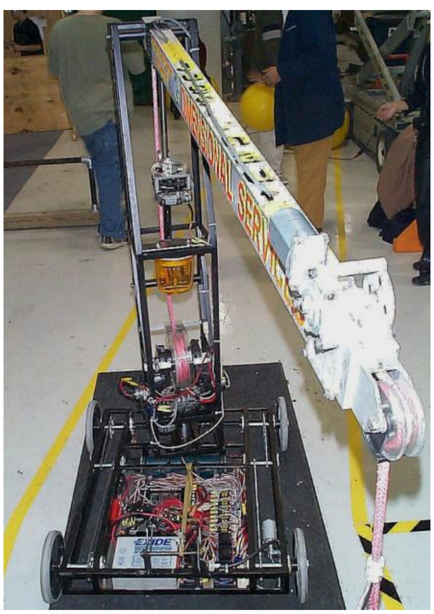

Figure 16: Make sure all components are laid out and mounted in an organized and sensible way. Good Luck!!!!!!

Section 12: Alternative Reading Material

Suggested Reading - Appendix B

There are a number of good references listed in the Robot Builder's Bonanza. Below are some newer ones not found there. This material is not just aimed at building robots for competitions, but for those looking at getting into the wonderful world of robot design and engineering. Robots are the wave of the future just like computers once were. I mean, those young people that have the farsightedness to get in on the ground level of something like domestic robot design have the potential for becoming the next Bill Gates of robotics. Bringing usable, practical robots to the consumer market is going to make someone a lot of money. Hopefully, it will be a student that got stimulated by competing in the Oakland County Competitive Robotics Association's Robot Competition.

Mobile Robots: Inspiration to Implementation
By: Joseph L. Jones, Anita M Flynn and Bruce A. Seiger
ISBN 1-56881-097-0; 486pp.; $32.00

Sensors for Mobile Robots
By: H. R. Everett
ISBN 1-56881-048-2; 528 pp.; $68.00

Navigating Mobile Robots
By: Johann Borenstien, H. R. Everett and Liqiang Feng
ISBN 1- 56881-066-0; CD-ROM version available; $44.00

Personal Robotics: Real Robots to Construct, Program and Explore the World
By: Richard Raucci
ISBN 1-56881-089-X; 200 pp.; $25.00

Build Your Own Robots
By: Karl Lunt
ISBN 1-56881-102-0; 450 pp.; $40.00

The Personal Robot Navigator
By: Merl K. Miller, Nelson Winkless and Joe Bosworth
ISBN 1-888193-00-X; 224 pp.; $44.95

The Complete Handbook of Robotics
By: Edward L. Safford, Jr.
ISBN 0-8306-1071-5; 358 pp.; $14.95

Magazine: Robot Science & Technology
MSC 253
2351 Sunset BLVD STE 170
Rocklin CA 95765-9977
Phone: (888) 510-7728

Figure 17: Designing a well laid out driver's station is no longer essential in OCCRA, particularly ifn you are only using the two VEX joystick controllers; if you are going to get really sophisticated and assign robot actions to the other sensors and switches, consider a more functional driver station. This makes driving the robot a pleasure rather then a chore and allows drivers to concentrate on the strategy of a match rather then the distractions of a hard to drive robot. Notice the handle at the top of the station that allows for easy transport on and off the field. Students should decorate and label the driver's station to make it an attractive addition to the overall robot system.