Alan Kilian Spring 2007

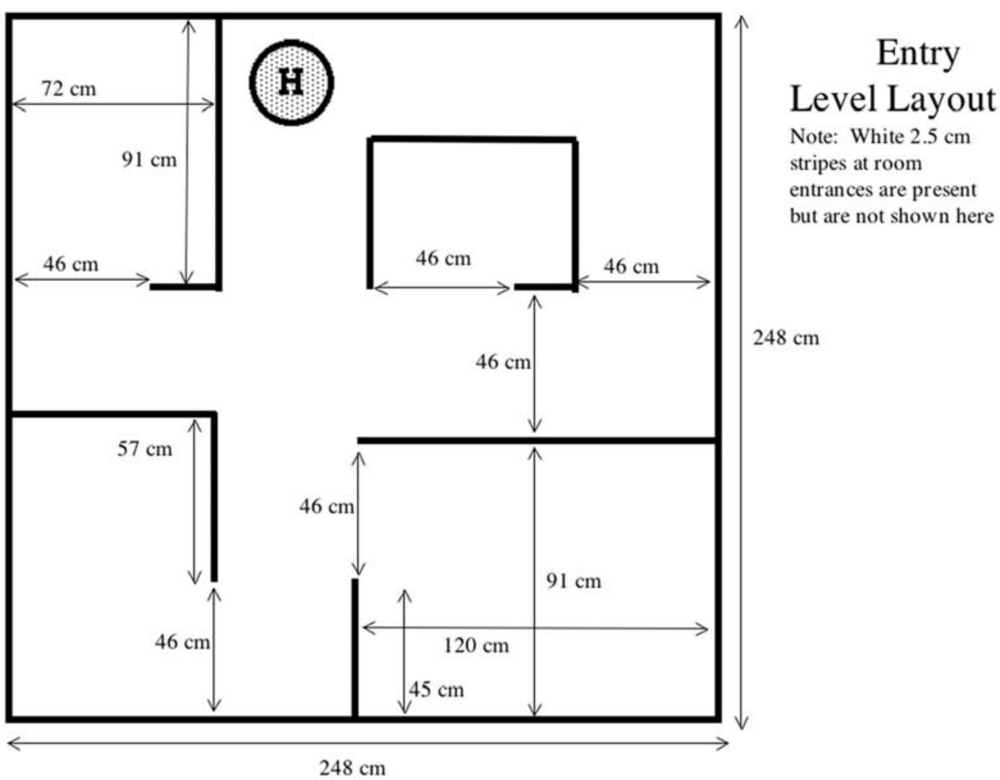
Design and construct a Holonomic motion platform and control system.

Introduction:

This project is intended as a demonstration of my skills in four specific areas: Power system design; electronic circuit design; printed circuit board design and mechanical system design.

Typically a robot is designed for a specific purpose such as painting an automobile or putting labels on cans. An undergraduate project such as this one does not have the luxury of a set of requirements for the robot and it is difficult to make up arbitrary requirements. In order to reduce the possible set of requirements to a set that is manageable I have chosen to design and building a robot capable of competing in the Trinity College robot fire-fighting competition. This competition has held annual competitions for 13 years and the rules have evolved into a clear, concise document. I am using the competition rules as a guide to help make design choices for the robot in this project even though I may never compete in the fire fighting competition.

The main goal in the Trinity competition is to create a fully autonomous robot capable of moving through a maze-like structure, find a lit candle and extinguish the flame.



The criteria I have selected from the Trinity rules are: (From the Trinity robot rules and edited by me)

6. ROBOT OPERATION

Once turned on, the robot must be autonomous--self-controlled without any human intervention. That is, they are to be computer controlled and not manually controlled devices.

A robot may bump into or touch the walls of the arena as it travels, but it cannot mark, dislodge or damage the walls in doing so. There will not be a penalty for touching a wall, but there is a penalty for moving along the wall while in contact with it. The robot cannot leave anything behind as it travels through the arena. It cannot make any marks on the floor of the arena that aid in navigation as it travels.

8. ROBOT SIZE

Robot must be able to fit in a box 31 cm long by 31 cm wide by 27 cm high. If the robot has feelers to sense an object or wall, the feelers will be counted as part of the robot's total dimensions. The robot cannot separate into multiple parts and must never extend itself beyond the 31 cm allowed.

There are hundreds possible configurations of mobile robots that will meet these requirements. Many of them can be used to build a robot capable of competing in this robot challenge. I have selected a Holonomic configuration for several reasons. I believe that the capability to move in any direction without changing orientation will enable simple navigation through the robot firefighting arena. Another reason that it is not a configuration I have used before and it will present challenges to me which will make the project more interesting than building another platform similar to others I have constructed before.

In this report, I will present the design of the robot called Trippy. I will explain the design choices I made and the results of those decisions.

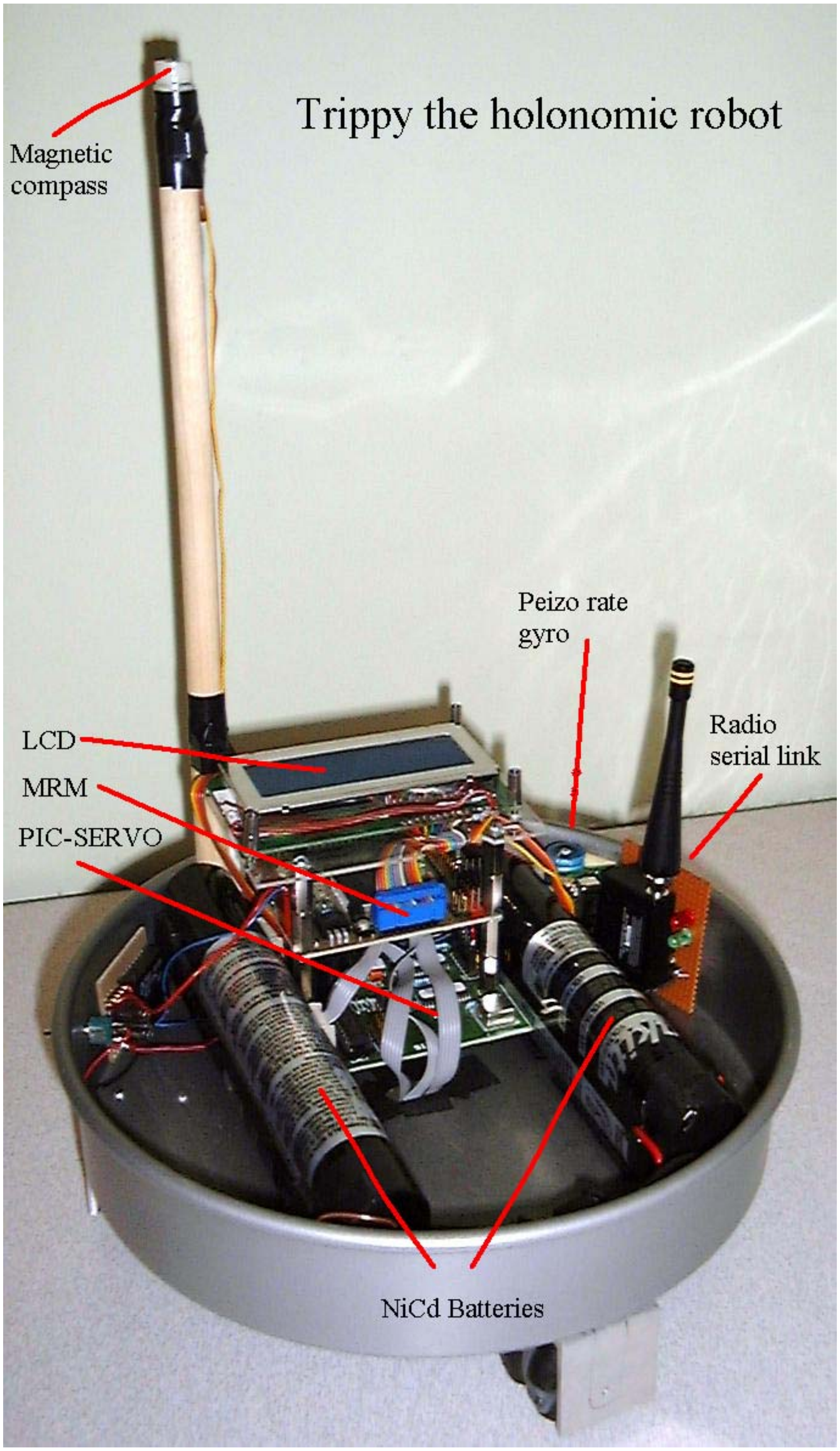


Figure 1 Trippy overview diagram (Early version)

Power system design:

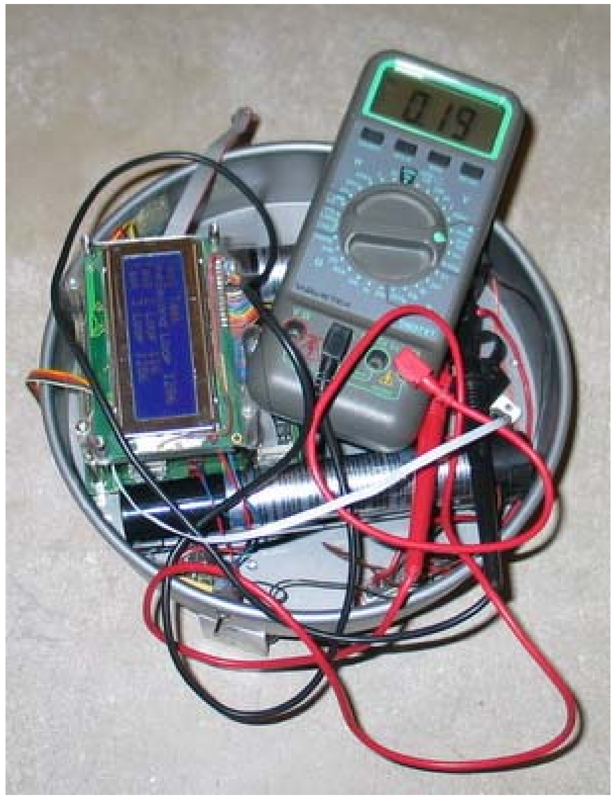
Demonstrate the ability to calculate a theoretical estimate of electrical power consumption, to design an appropriate power source, to construct a power source and to measure the performance of the power source, verifying that it meets the design goal of providing enough power to run the robot for 30 minutes.

Trippy has several types of power consuming devices: motors, main processor, motor-control processors and a display. I measured the power consumed by these devices under normal operating conditions and found that a single motor uses 360 milliWatts when running without a load, and 1,000 milliWatts when I slowed the motor down with my hand to simulate a load. The processor, motor-control processors and display use 2,000 milliWatts when running a test program. A robot with three fully loaded motors and the other devices should consume (1,000 * 3) + 2,000 = 5,000 milliWatts of power. The power required to run this robot for 30 minutes is 5,000 milliWatts * 0.5 hours = 2,500 milliWatt-Hours.

Power for the robot is provided by rechargeable NiCd batteries. This robot will need a minimum of 2,500 milliWatt-Hours of battery power. Designing a NiCd battery charging system is not complicated, but I decided to save the effort and adapt a commercial battery pack and commercial charging system to save time and effort. I purchased a Makita brand external charging system and two Makita brand NiCd battery packs rated at 9.6 Volts and 1500 milliamp-Hours. Each battery pack can produce 14,400 milliWatt Hours. I used two battery packs, so the power system is capable of providing approximately 29,000 milliWatt-Hours of power. This design is significantly over-rated for the task of providing power for the robot for 30 minutes of continuous operation, and provides a good margin of excess power for unanticipated loads such as sensors and communication devices that may be added in the future.

The Makita battery packs are designed to be removed from the device they power when they need recharging. They are then inserted into a charger and reinserted in the device when recharging is completed. I did not want to disassemble the robot to recharge the batteries, so I needed to design and build a connection method to charge the batteries inside the robot. First, I disassembled the Makita chargers and drew a schematic diagram by looking at the printed circuit boards. This schematic showed the three connections to each battery I needed to use so I could design a connector to allow me to plug both chargers into the robot and charge the batteries without having to remove them. I constructed a cable using a DB-25 connector that plugs into the bottom of the robot and charges the batteries as though they were inserted into two separate charging units.

Actual current was measured on September 28 2007 and was found to be 190 milliAmps when measured at the 18.5 Volt DC supply.



This is a power draw of 3.5 Watts which is less than the estimated value. The robot was placed on a concrete floor and ran in a circle for 30-minutes. After this demonstration, the battery voltage measured 18.4 Volts DC.

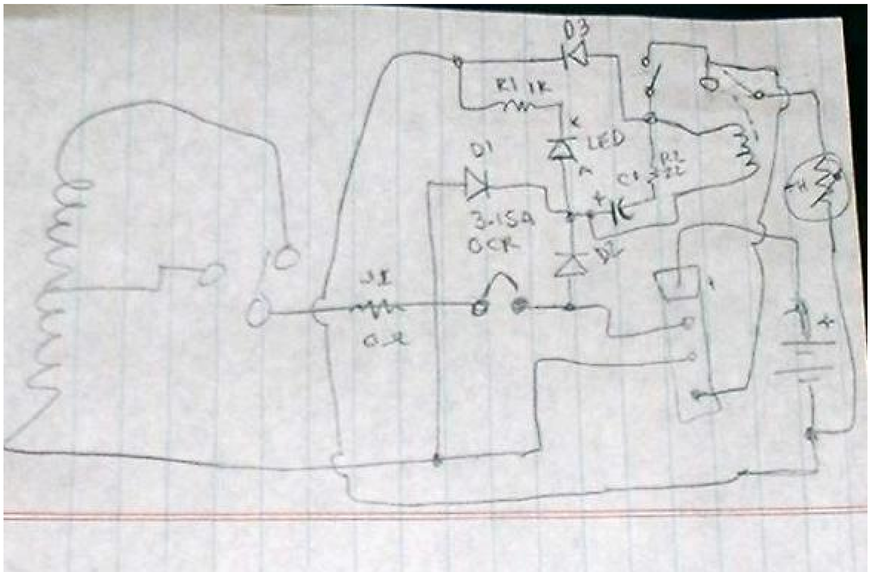


Figure 2 Makita NiCd battery charger schematic.

Figure 3 Trippy battery and external charging system.

Electronic circuit design:

Demonstrate the ability to select electronic components suitable for use in implementing a closed-loop control system for small electric motors.

In my previous project, I used the J.R. Kerr PIC-SERVO set of integrated circuits to build a compact PID control system for small DC motors with optical encoders, and I decided to use that experience to design a three-channel controller using the same parts.

I used the sample schematic from the J.R. Kerr website for a single-channel controller and duplicated the circuit four times to create a 4-channel system. I chose to implement one more channel of PID motor control so that if I need an additional channel to control another motor, I will have it available. This design choice did not use up significantly more space than a 3-channel design.

I used the Eagle schematic capture and PCB layout software from Cadsoft USA to enter the schematic design and to check it for electrical correctness.

There were only two design choices necessary at this stage. I needed to select a motor driver chip and I needed to design a method to communicate to all 4 PID servo controller chips from a single communication interface.

I selected LM293D motor driver chips since I used them in a previous project with the J.R. KERR PIC-SERVO chips and they worked well. They also can provide the required current to drive the selected motors.

I used an example circuit from the J.R. KERR reference design to implement the communication circuit. The design of the PIC-SERVO chipset allowed me to connect a single transmit signal from the main processor to all of the PIC-SERVO chips and to address each chipset individually using a unique number. This reduced the complexity of the interface between the main processor and multiple PIC-SERVO chipsets.

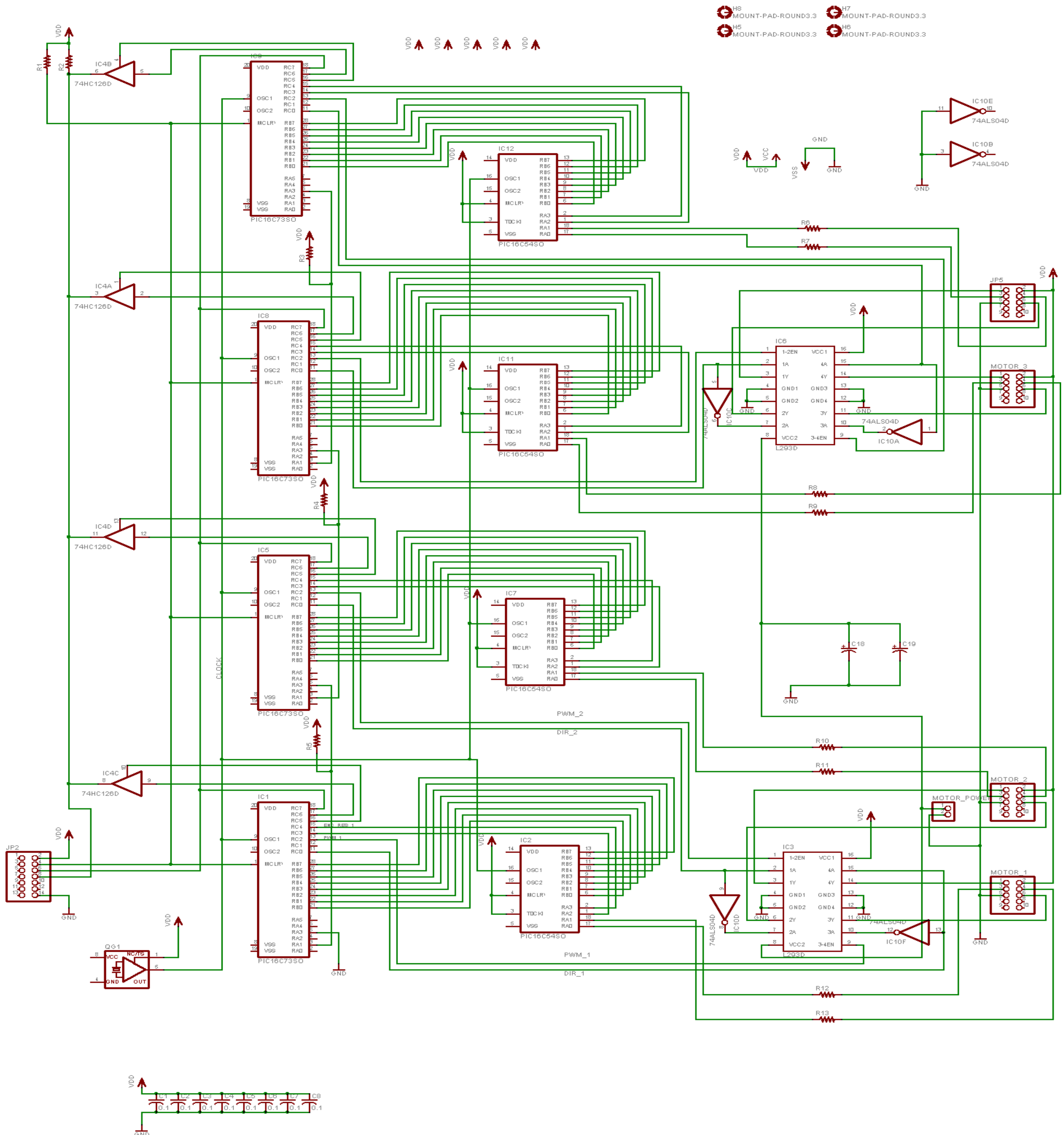


Figure 4 Complete schematic

Printed circuit board design:

Demonstrate the use of printed circuit board design tools at an intermediate level.

J.R. Kerr now sells the chips I used in the previous project in a Small Outline Integrated Circuit (SOIC) package which is significantly smaller than the Dual Inline Pins (DIP) package I used previously.

Initially, I designed a small narrow printed circuit board, and intended to attach three of the boards to the triangular design as follows:

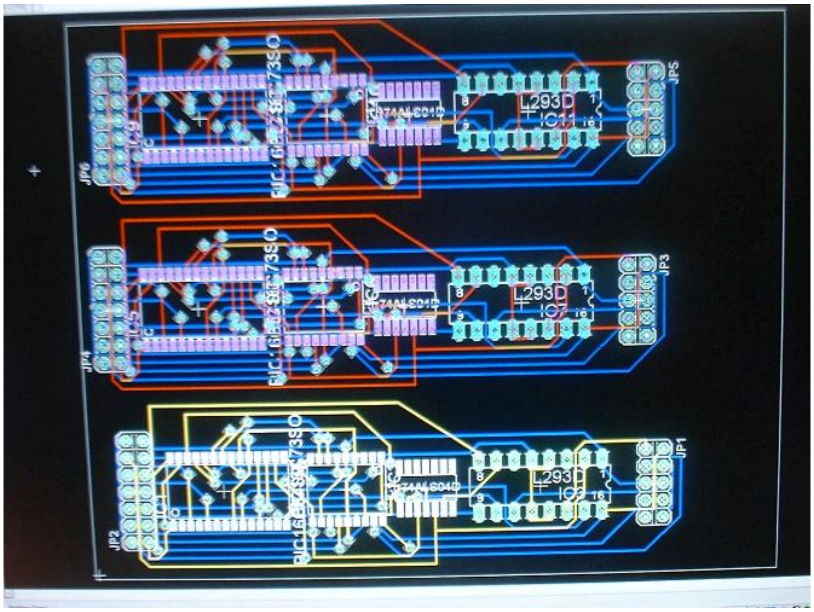


Figure 5 Initial PCB design.

Figure 6 Initial PCB placement on robot.

This design has aesthetic advantages, but the mechanical complexities involved in mounting and cabling made me decide to use a more conventional rectangular format for the printed circuit board.

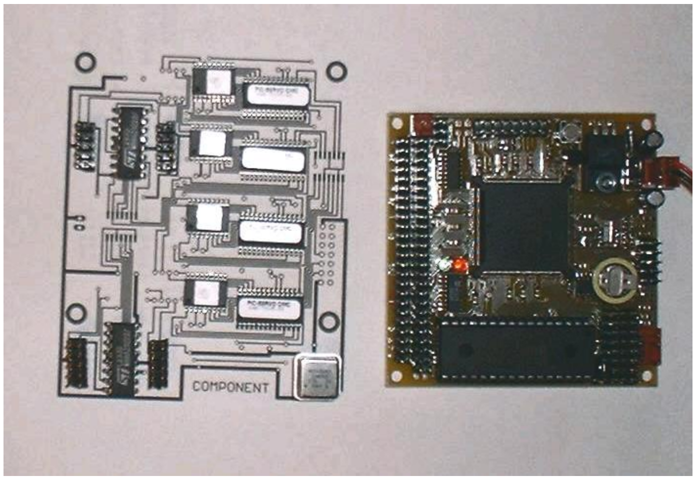


Figure 7 Final PCB design with processor board.

I used the Eagle package to place the parts on a circuit board layout and move them around so that the length of interconnecting wires was minimized. I also verified the placement of the motor and controller connectors was appropriate to the length of motor cables.

Initially, I used the Eagle auto-routing function to perform the layout. This makes creating a functional design easy, although the router does not make any special provisions for creating human-readable layouts. It routs the board efficiently, but traces can move from one layer to another underneath chips and several times before reaching their destination. This makes the boards difficult to debug if there is an error in layout.

This example using the auto-routing feature created a board with approximately 100 vias where a trace changed layers. Fewer vias are desirable in that they reduce the cost of the board and make it easier to debug.

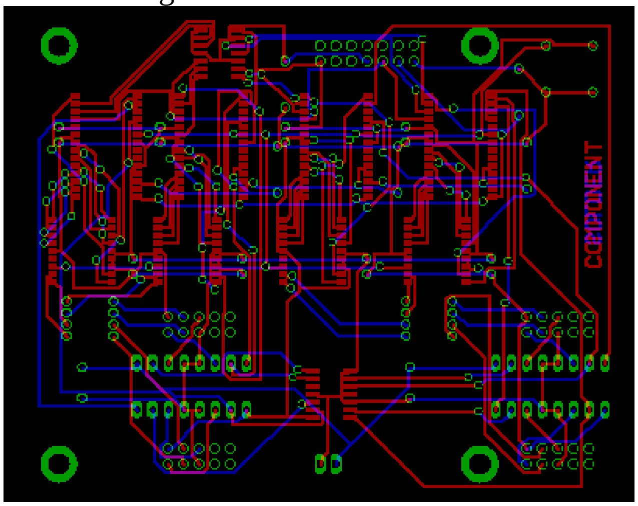


Figure 8 Auto-routed layout

This hand-routed board by Jeffry Sampson contains about 60 vias.

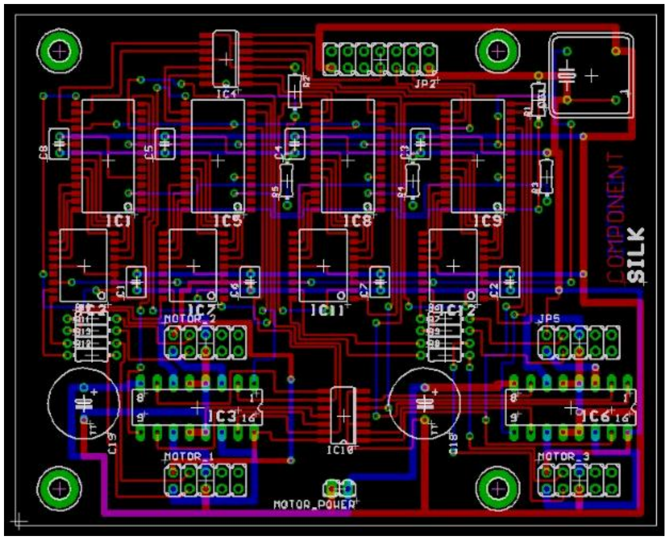


Figure 9 Final layout

In addition to reducing via count, we were able to select larger traces for high-current paths that supply power to the motor drivers and connect the motor drivers to the motor connectors. This improves reliability of the system.

The boards were fabricated in Bulgaria by the Olimex Company.

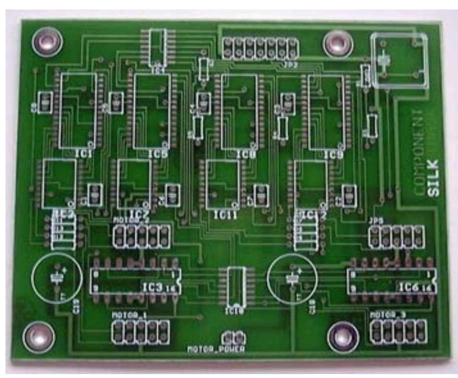


Figure 10 Final PCB Front.

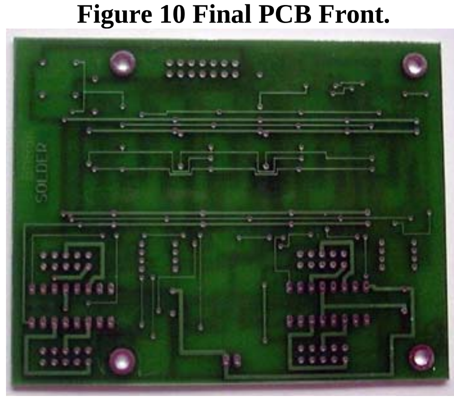


Figure 11 Final PCB back

The Olimex PCB fabrication company is inexpensive, but does not produce error-free circuit boards, so it was necessary to inspect the bare PCBs and look for errors.

Using front and back lighting, I inspected every trace and found several easily corrected errors.

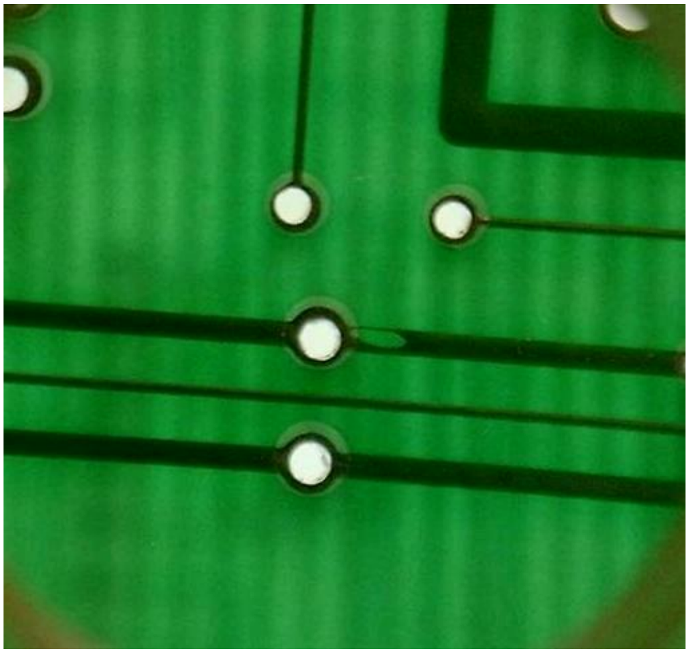


Figure 12Void in the PCB trace.

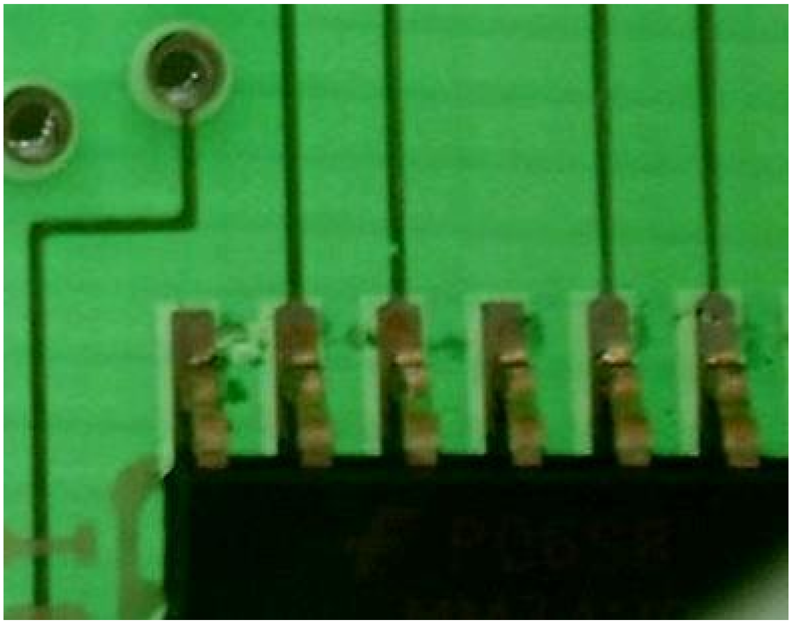


Figure 13Small nick in PCB trace.

This was the first time I attempted to assemble a PCB using surface mount, and it presented some challenges, but none were insurmountable.

I setup a magnifying glass with light and started soldering parts onto the PCBs

Figure 14Soldering setup

Figure 15Checking continuity on PCB

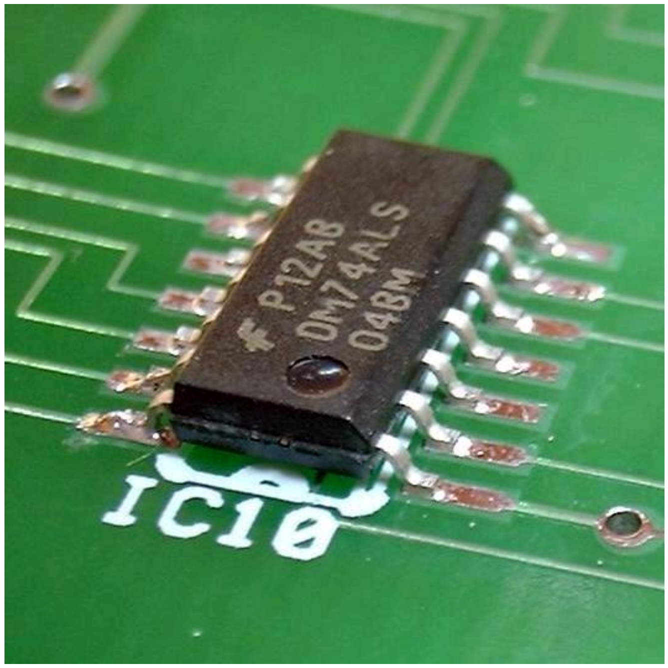


Figure 16 Soldering the first IC

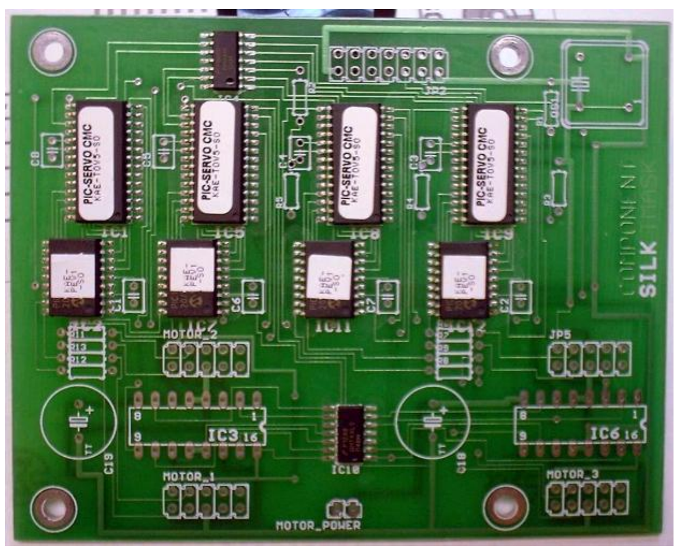


Figure 17 All surface mount ICs soldered

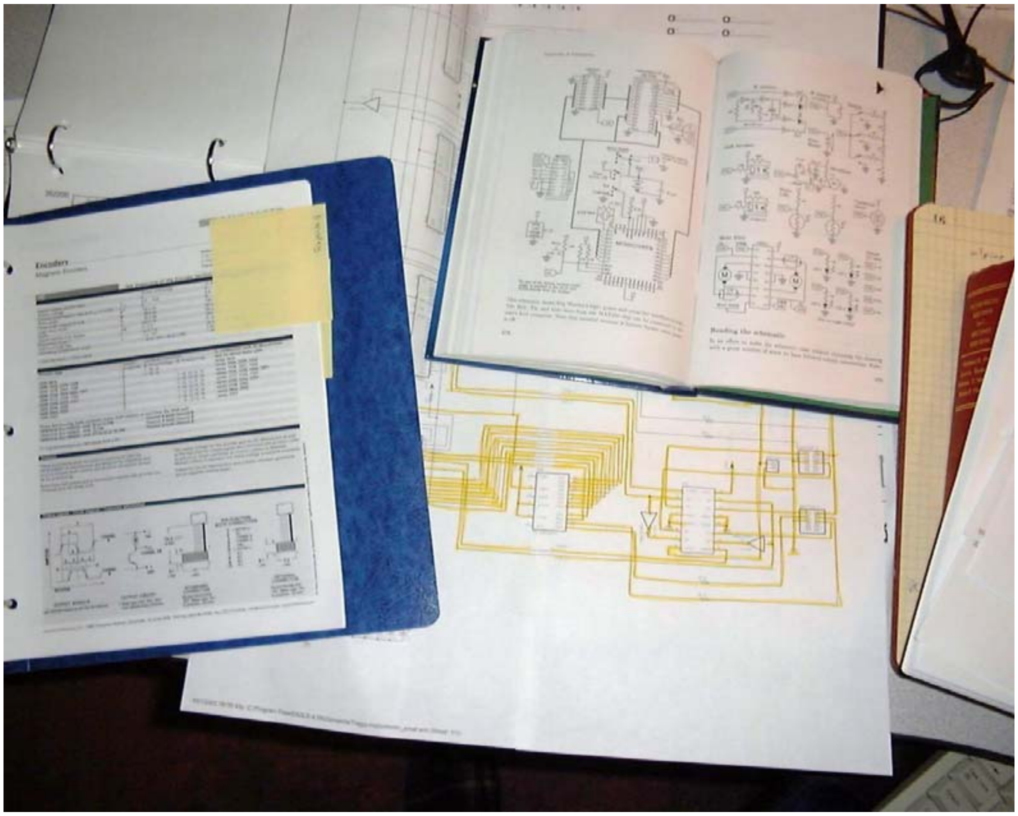


Figure 18Reference manual, schematic and book reference

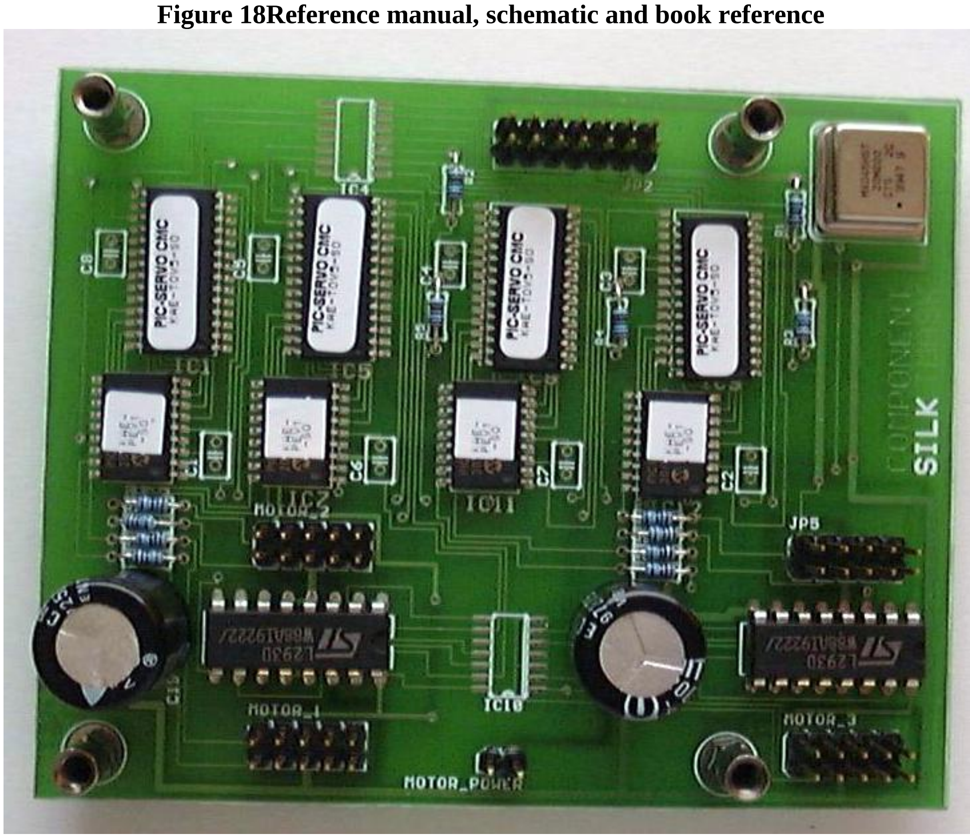


Figure 19Completed motor driver board

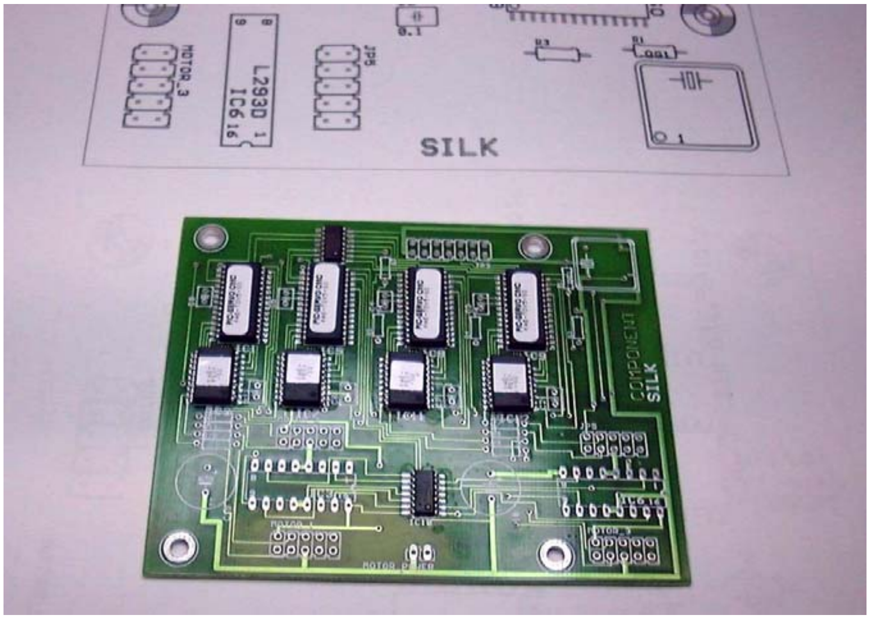


Figure 20motor driver board and reference print

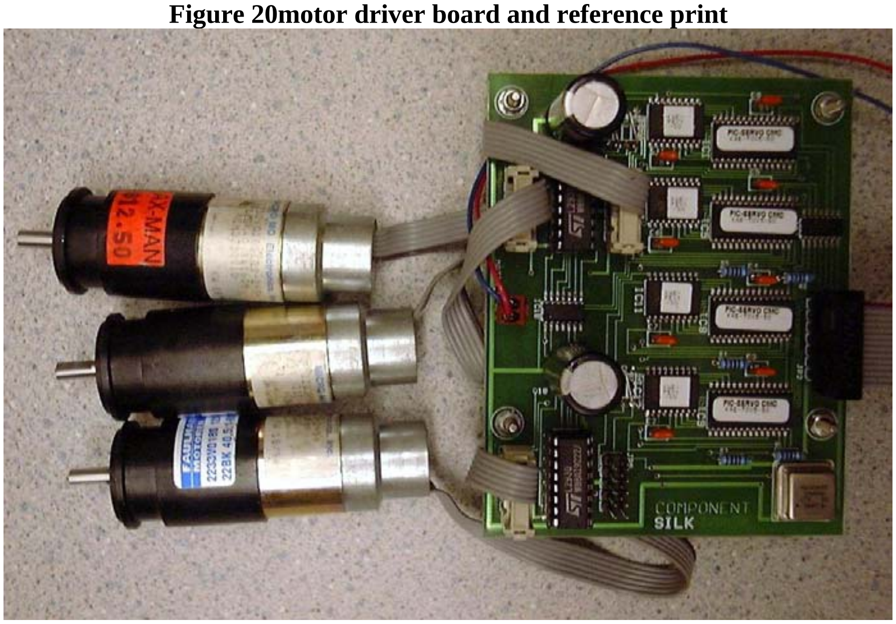


Figure 21Complete motor driver board with motors

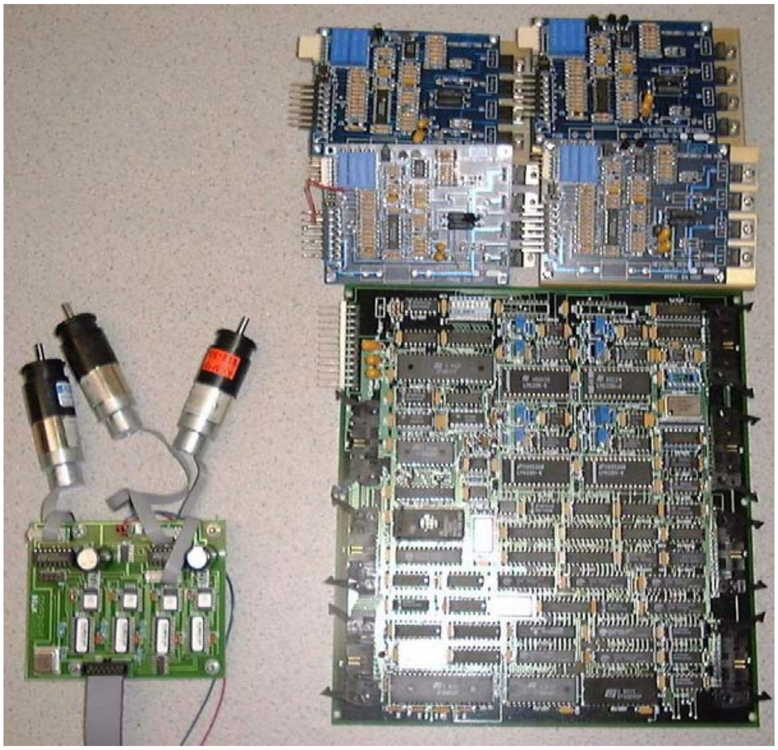


Figure 22Motor driver board compared to commercial motor driver board

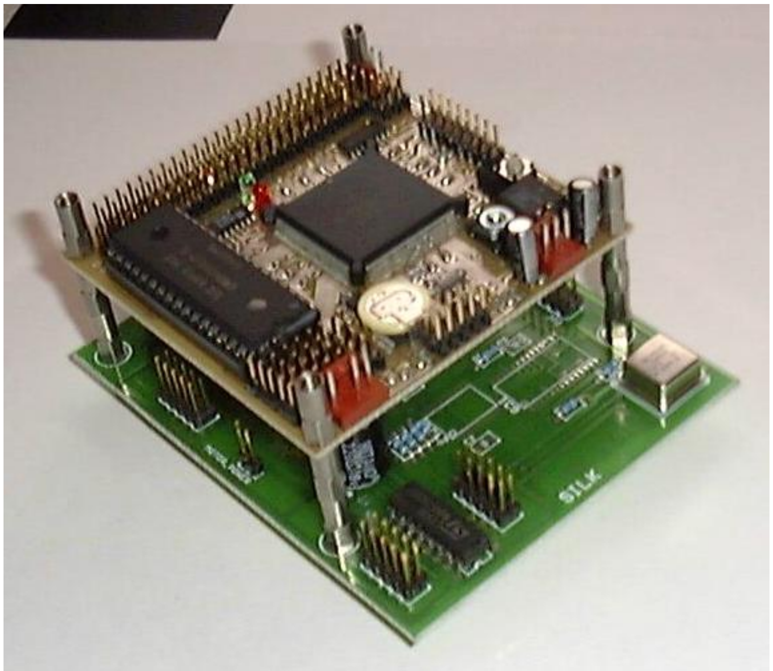


Figure 23Motor driver board and CPU stacked

Mechanical system design:

Demonstrate the ability to select mechanical components, fabricate machined parts and assemble a simple working mechanical system.

Figure 24Palm Pilot Robot inspiration

The Palm Pilot Robot Kit (PPRK) available on the internet was my inspiration for the wheel design for Trippy. It uses hobby servos to directly drive the wheels. This design has several disadvantages. All the weight of the robot produces torque on the output shaft of the hobby servo and will increase the wear on the output bearings and will result in failure of that part of the mechanical system. I designed a mechanical system that supports the robot weight on two bearings so that there will be no torque on the motor output shaft.

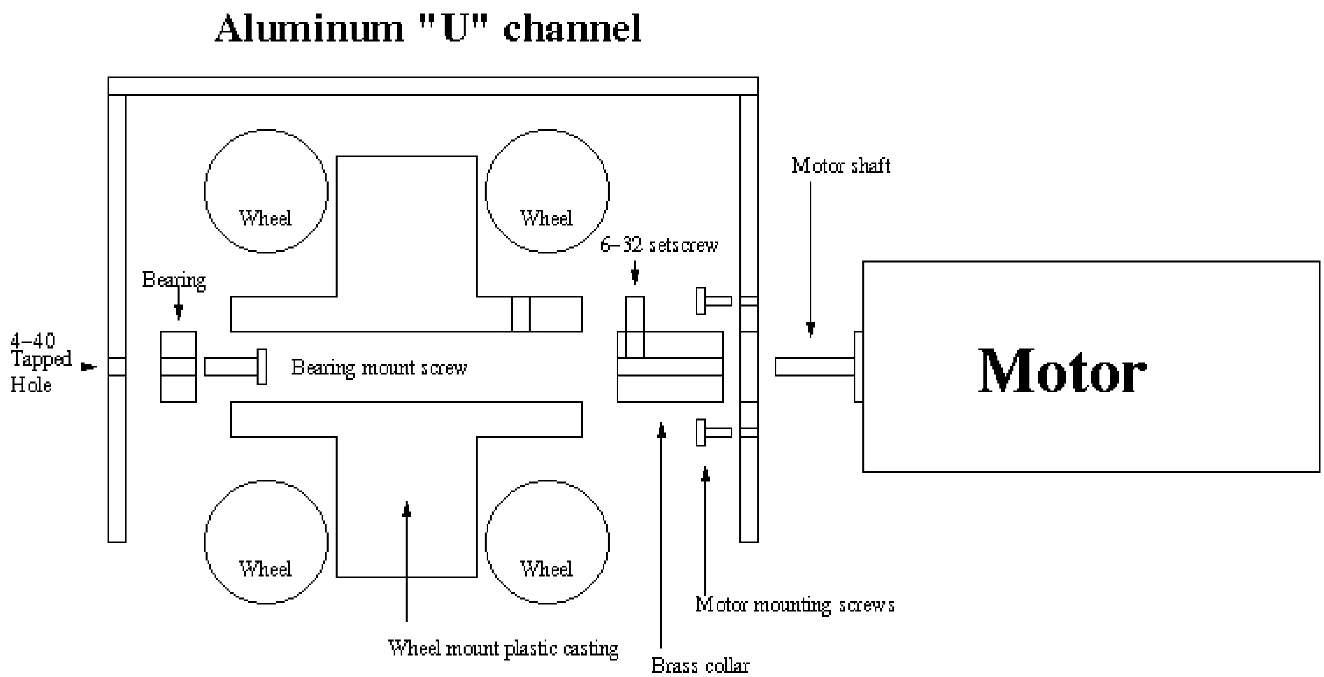
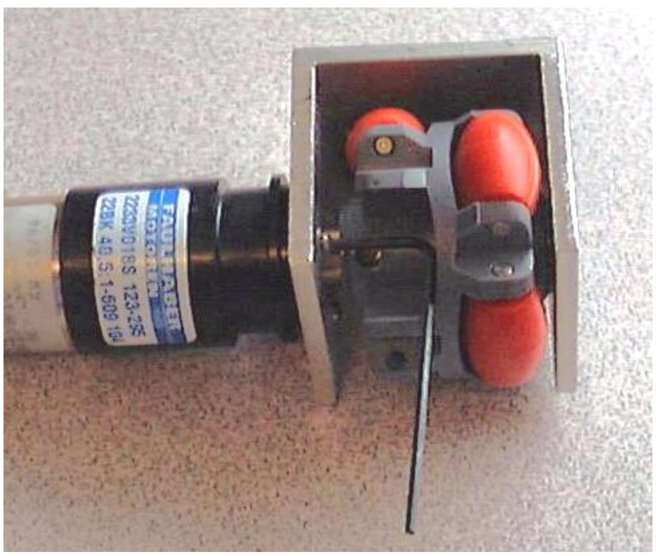


Figure 25 Trippy wheel mechanical design

This mechanical design is sturdy and easily constructed with simple tools. It is easy to align the motor shaft with the end bearing, and remains in alignment without needing periodic adjustment. The entire mechanical assembly can be removed from a structure and reattached without needing any disassembly. This design has one rather major flaw in that it is very difficult to assemble or disassemble. The following images show the steps required to replace a wheel assembly.

One roller pin must be removed by pressing out the roller-pin shaft.



The motor mounting screws need to be removed using the gap in the wheel assembly left when the roller was removed. The two upper mounting screws are very difficult to reach, and the Allen wrench can only be turned a few degrees before hitting another part of the structure.

The inner bearing retaining screw needs to be removed using a long thin screwdriver through a hole in the wheel assembly.

Figure 26 The final disassembled wheel structure parts prior to reassembly using rubber roller wheels.

Figure 27 Rubber roller with roller removed

This design was difficult to assemble and maintain. Needing to press out shafts to access the motor mounting screws proved to be a great hindrance to wheel replacement. This design could be improved if the aluminum “U” structure was split into two “L” shaped structures mounted to a flat plate. This way, the outer bearing holder could be removed; the wheel slipped off its hexagonal driving shaft and the motor mounting screws would be easily accessed. The new design has the disadvantage of needing to be aligned when assembled. Depending on the design requirements for assembly and serviceability, one of these two designs would be better than the other.

The initial mechanical structure for Trippy was a triangular base constructed of aluminum "U" channel with a wheel assembly at each end. This is a pleasing setup to look at, but would have required externally mounted batteries and electronics.

Figure 28 Initial triangle prototype

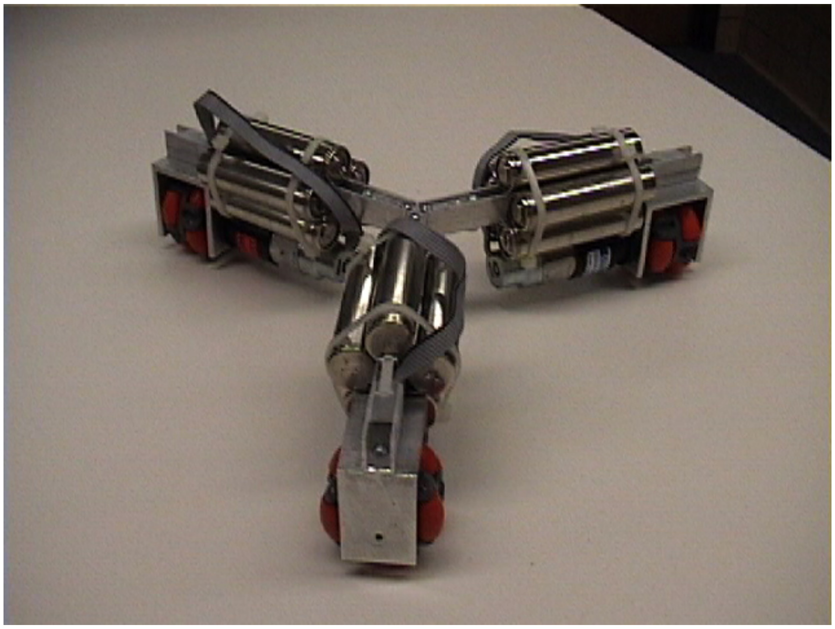


Figure 29 Prototype with battery packs

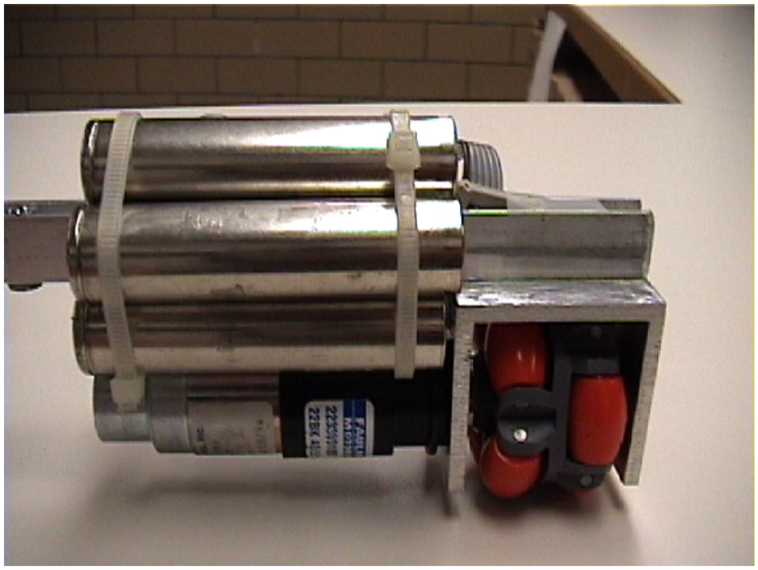


Figure 30 Prototype one wheel

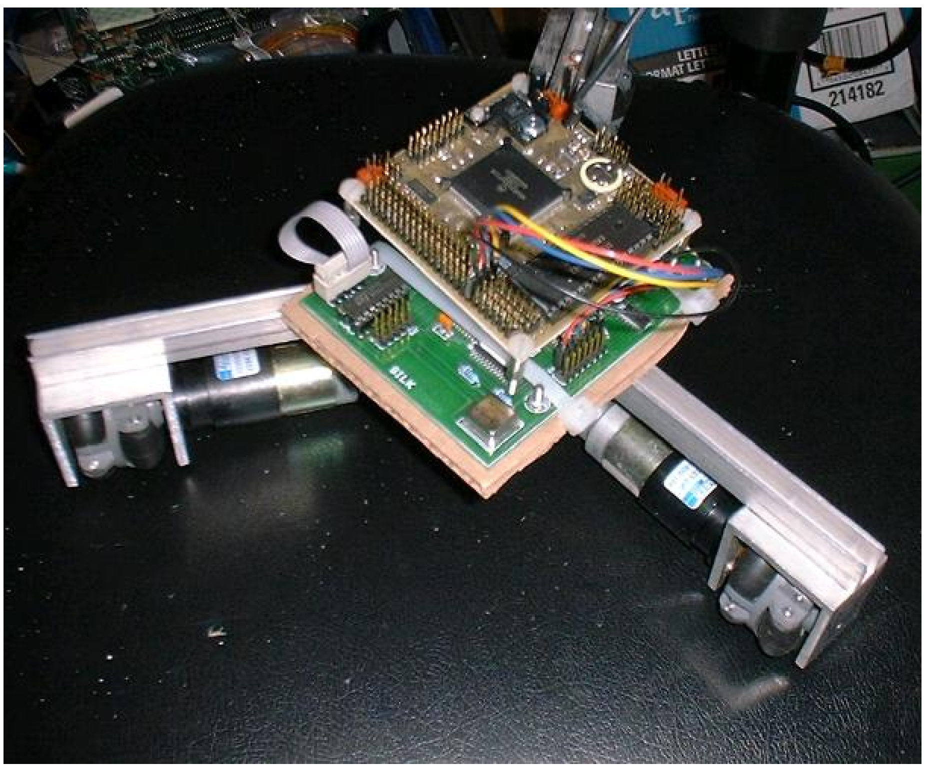


Figure 31Initial design motor controller and CPU

I decided it would be better to enclose the batteries and electronics in a metal box to protect them as well as to protect anyone touching the robot.

Figure 32 Final mechanical assembly

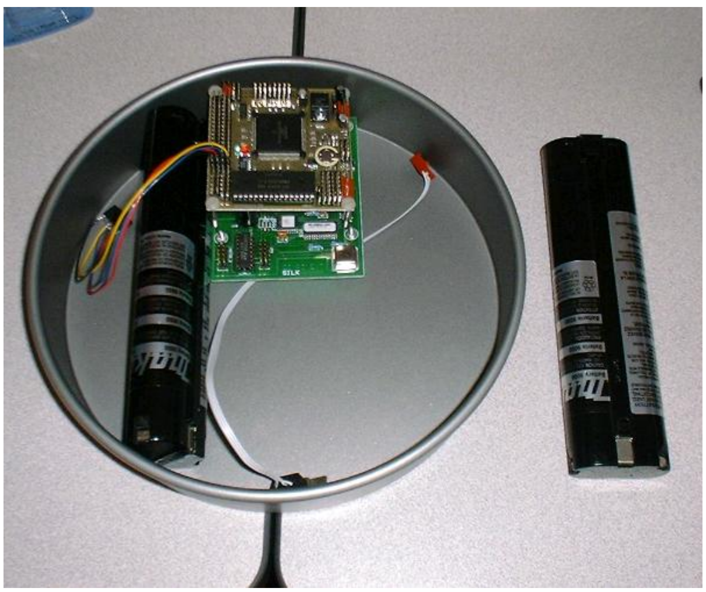


Figure 33Final design motor controller, CPU and batteries

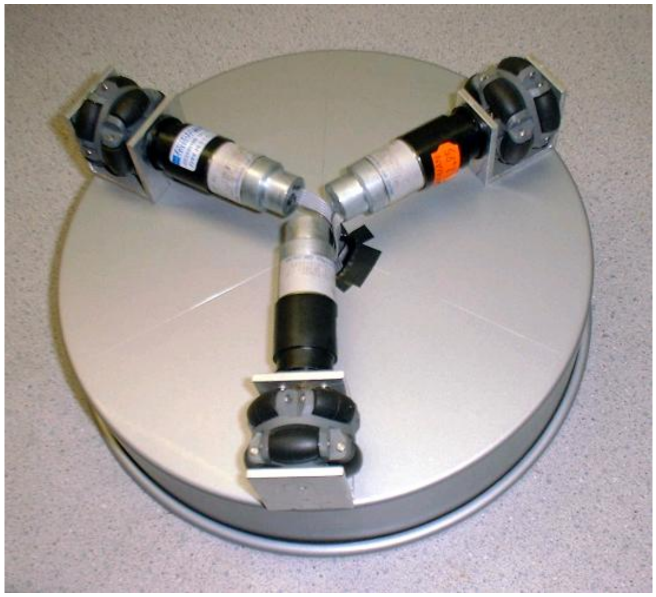


Figure 34Final design underside

The final design incorporates two aluminum trays designed for baking cakes. These trays are just the right size to hold the battery packs, the motor controller PCB, the processor PBC, and the LCD module with enough extra room for a radio and gyroscope which will be added in a later project.