Beyond the Horizon

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November 9, 2000

Dr. Andrew Rawicz

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Re: ENSC 340 Design Specification for StairCraft – a Stair-Climbing Mechanism

Dear Dr. Rawicz:

The attached document, *StairCraft Design Specification*, elaborates on the Functional Specification Document submitted earlier. Our original goal was to build a full scale stair-climbing (up and down) mechanism that can be incorporated onto a wheelchair. However, it is too complex and time-consuming for a 4 months project course. As a result, we at Beyond the Horizon, have decided to downscale our project goal – to build an automated mechanism that can climb up stairs while keeping the top platform horizontal throughout the process.

The design specification discusses the method we will pursue in order to achieve the functional specification described previously. For example, the system components include the mechanical structure and framework, user interface, signal acquisition unit, input/output signal conditioning unit, controller unit, and actuator unit.

Beyond the Horizon consists of six talented, innovative and enthusiastic fourth-year systems engineering students – Wayne Chen, Kenneth Cheng, Jeff Hsu, Andy Ma, Michael Tam, and Gordon Yip. If you have any questions or concerns about our document, please feel free to contact any of us by emails at staircraft-340@sfu.ca or contact me by phone at (604) 926-6600 or by e-mail at kchengc@sfu.ca.

Sincerely,

Kenneth Cheng
Team Manager
Beyond the Horizon

Enclosure: Design Specification for StairCraft – a Stair-Climbing Mechanism

Beyond the Horizon

presents

STAIRCRAFT™

a Stair-Climbing Mechanism

Design Specification

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Executive Summary

At Beyond the Horizon, the ultimate goal is to build an automated wheelchair that can climb up and down stairs or steps so physically challenged people can go to places that existing wheelchair cannot take them. The system has to be relatively affordable by most households and more importantly it has to be safe and simple to use.

However, due to our limited budget and time, we are forced to downscale our ultimate goal to fit the purpose of this course. As a result, at the end of this semester, instead of building a fully automated stair-climbing machine, we are going to build part of the final product – an automated mechanism that can climb up stairs while keeping the top platform horizontal throughout the process.

For this project, we are going to build the frame with aluminum plates and acrylic plastic board. Ultrasonic sensors are used to detect upcoming steps. Once the signal has been acquired via the ultrasonic sensors, we will condition (amplify and filter) it before feeding the cleaned input signal into our logic gates and microprocessors. The output signal from the logic gates and microprocessor will then control the DC motors and power the car jacks to give us the desired vertical motion.

The following document outlines the implementation of all parts of the downscaled StairCraft and discusses the details of system testing.

Table of Contents

EXECUTIVE SUMMARY .... **I**

1 INTRODUCTION **1**

2 MECHANICAL DESIGN & ANALYSIS **2**

2.1 OVERALL STRUCTURE 2

2.2 PROBLEM REFINEMENT 3

2.3 MECHANICAL COMPONENTS 4

2.4 STRUCTURAL ANALYSIS 7

2.5 SEQUENCE OF OPERATION 10

3 SENSORS, CONTROLLERS, AND ACUTATORS **13**

3.1 SENSOR SELECTION 13

3.2 SENSOR INPUT CONDITIONING CIRCUIT 13

3.2.1 40kHz Oscillator 14

3.2.2 AC Amplifier 15

3.2.3 40kHz Band-pass Filter 15

3.2.4 Full-wave Rectifier 16

3.2.5 Low-pass Filter 17

3.2.6 Voltage Amplifier 17

3.2.7 Output Buffer 18

3.3 SIGNAL PROCESSING CIRCUIT 19

3.4 MOTOR DRIVE CIRCUIT 21

4 USER INTERFACE **23**

5 CONCLUSION **23**

List of Figures

FIGURE 1: 3-D SHADED VIEW OF STAIRCRAFT 2
FIGURE 2: 3-D WIRE FRAME VIEW OF STAIRCRAFT 3
FIGURE 3: 3-D VIEW OF A 2 IN DIAMETER RIGID CASTER 5
FIGURE 4: 3-D VIEW OF A 2 IN DIAMETER SWIVEL CASTER 6
FIGURE 5: 3-D VIEW OF A TYPICAL SCISSORS JACK (NOTE: SCREW IS NOT SHOWN) 6
FIGURE 6: 20 IN BY 15 IN ACRYLIC PLASTIC PLATFORM 7
FIGURE 7: ¾ BY ¾ ALUMINUM PLATE 7
FIGURE 8: CLEARANCE OF SENSING RANGE OF VERTICAL SENSORS 8
FIGURE 9: CLEARANCE OF SENSING RANGE OF HORIZONTAL SENSORS 9
FIGURE 10: ESTIMATION OF SENSING RANGES IN OPERATION 9
FIGURE 11: STAIRCRAFT IN OPERATION 12
FIGURE 12: BLOCK DIAGRAM FOR THE SENSORY CIRCUIT 14
FIGURE 13: CIRCUIT SCHEMATIC OF THE AC AMPLIFIER 15
FIGURE 14: CIRCUIT SCHEMATIC OF THE 40KHZ BAND-PASS FILTER 16
FIGURE 15: CIRCUIT SCHEMATIC OF THE FULL-WAVE RECTIFIER 17
FIGURE 16: CIRCUIT SCHEMATIC OF THE LOW-PASS FILTER 17
FIGURE 17: CIRCUIT SCHEMATIC OF THE VOLTAGE AMPLIFIER 18
FIGURE 18: CIRCUIT SCHEMATIC OF THE OUTPUT BUFFER 19
FIGURE 19: SENSOR AND MOTOR LOCATIONS IN STAIRCRAFT 19
FIGURE 20: THE CLIMBING SEQUENCE CONTROL HARDWARE. 21
FIGURE 21: MOTOR DRIVE CIRCUIT SCHEMATIC 22

List of Tables

TABLE 1: TABLE OF REQUIRED MECHANICAL COMPONENTS 5

1 Introduction

There is a common problem for existing wheelchairs – they cannot travel up and down stairs. As the people on wheelchairs approach staircases, they either have to find an elevator or a ramp nearby, or they simply have to turn around and head back to where they came from.

Beyond the Horizon's StairCraft is a low cost, reliable and safe stair-climbing mechanism. The special feature that separates our system from most other stair-climbing mechanism is that StairCraft keeps the platform horizontal during the stair-climbing process. As a result, our product can be incorporated into wheelchairs, robots, or cargo-transporters.

By the end of this semester, we are planning to finish the climbing-up-stairs portion of the final product due to our limited time and budget. Our primary goal is to explore the usability and reliability of our mechanism. Thus, we are going to build a smaller prototype instead of constructing the intended final version's size. Consequently, we can cut down the cost of building such system.

This document discusses the design specification for the main functional blocks of the electrical requirements as well as the physical, mechanical, and safety performance specifications of the system.

The purpose of this document is to describe the design specifications of StairCraft and explain the implementation of each component of the system in addition to discussing system testing. This document has been prepared by the design engineers of Beyond the Horizon for internal reference and for external distribution to Andrew Rawicz, Steve Whitmore, Jason Rothe, James Balfour, and other external design consultants.

2 Mechanical Design & Analysis

2.1 Overall Structure

The prototype that we will manufacture by December is a scale-downed version of the real craft. Figure 1 and 2 show the 3-dimensional mechanical structure of the prototype at different angles.

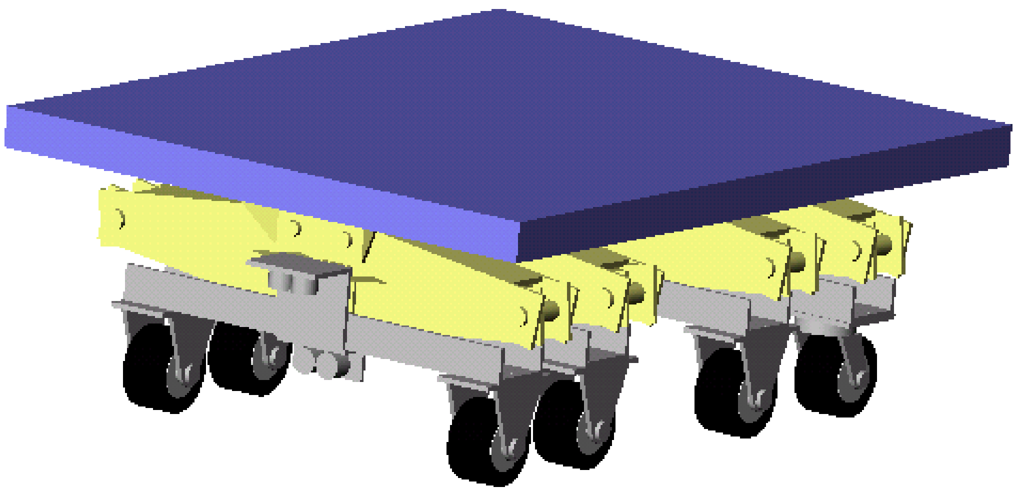


Figure 1: 3-D shaded view of StairCraft

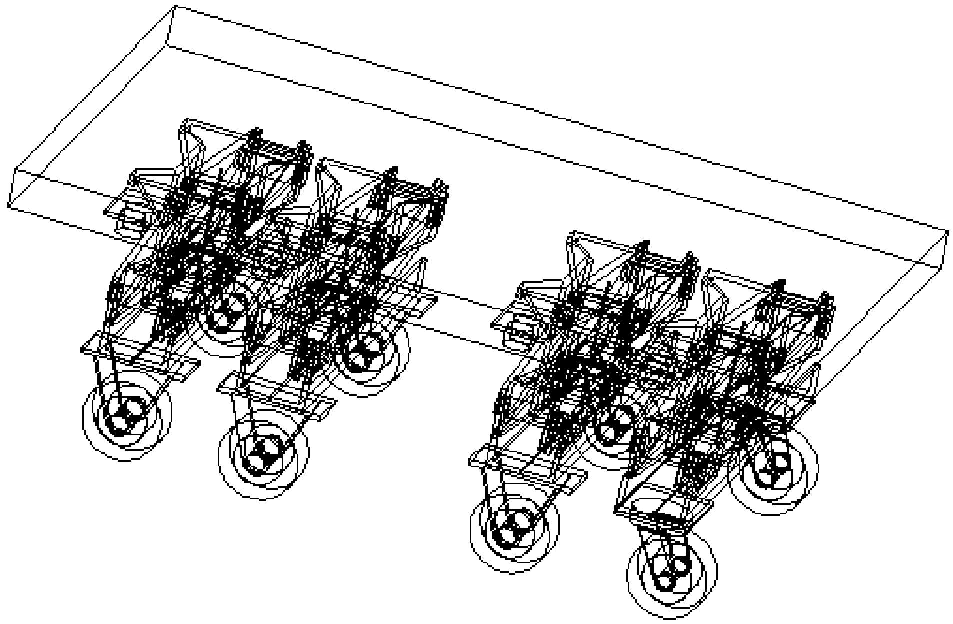


Figure 2: 3-D wire frame view of StairCraft

2.2 Problem Refinement

Due to the limited time and available resources we can find based on our budget for this project, our team has decided to scale down the problem. Originally, for the stair climbing problem of the wheelchairs, we have proposed to build a device that has the size of a electrical wheelchair. Hence, the real model was supposed to have a 3 ft by 2 ft platform, an elevation mechanism capable of rising 2 ft or more of heights controlled by high speed and high torque motors with approximately 600 rpm and 15 lb-ft or greater. Furthermore, our driving mechanism for travelling on flat surfaces would have consisted of smaller sized motors, and casters of 4 inches in diameters. The main advantage for scaling down the problem is that we can build a more portable prototype for our testing. Most importantly, we can save a lot of money and time when all of the project's requirements are simplified. In fact, if we were to simulate the real situation of the problem, we would have to build a mechanism that can rise at least 2 ft. From our research on various rising mechanisms, we concluded that we would need to design, carry out the dynamic analysis, manufacture, and perform testing on the mechanism ourselves. Therefore, we believe it is more appropriate to use some existing elevation mechanisms and reduce other requirements accordingly to generate a scale-downed prototype. We can always build the real device that can be applicable to the wheelchairs in the future when more time and resources are accessible.

We have considered several existing lifting mechanisms such as hydraulic actuators and z-shaped car jacks that may be applicable to our project. Because of the geometry and cost-effective reasons, we decide to choose and slightly modify the scissors car jacks as the actuators of our device. The existing symmetrical scissors jacks are capable of lifting a load of about 1320 lbs to 1 ft high. Therefore, the jacks suit our testing purpose of the prototype. Furthermore, the scaled down factor from the real case with the use of these jacks is approximately ½ because the height requirement is halved.

Although the jacks have a load capacity of 1320 lbs, it may seem redundant in real life application because users' weights usually range from 100 to 300 lbs. Hence, the operative load on our scale-downed prototype will be no more than 90 lbs. As the sizes of the casters decrease, the maximum load capacity of each caster reduces too. The diminished operative load reduces the motor requirements accordingly since the motors do not need to produce as high torque as before in order to drive the heavier load. Therefore, the expenses of this project are greatly reduced and we can locate motors that meet the scaled down requirements for our prototype testing.

The sizes of the platform, frames, shafts, and other structural components are thus roughly scaled down by a factor of one half the original sizes. In the following section, the numbers and general descriptions of each mechanical component used to build StairCraft will be provided. Our analysis will show that our ½ scale-downed version of the prototype will still be valid to simulate the stair climbing solution for the wheelchairs.

2.3 Mechanical Components

Table 1 lists the mechanical components that will be required to build StairCraft. See the respective figure for the picture of the component.

Table 1: Table of required mechanical components

Components	Number Used	Figures	Description
Rigid Casters	6	Figure 3	2 in diameter, 90 lb capacity, soft rubber wheel
Swivel Casters	2	Figure 4	2 in diameter, 90 lb capacity, soft rubber wheel rotating in 360°
Jacks	4	**Figure 5**	1320 lb capacity, height range from 3 ½ to 12 ¾ in
Platform	1	**Figure 6**	20 in by 15 in acrylic plastic
Plates	N/A	Figure 7	¾ in by ¾ in aluminum plate, thickness 1/8 in
Motors	5	N/A	Variable speeds from 325 to 650 rpm

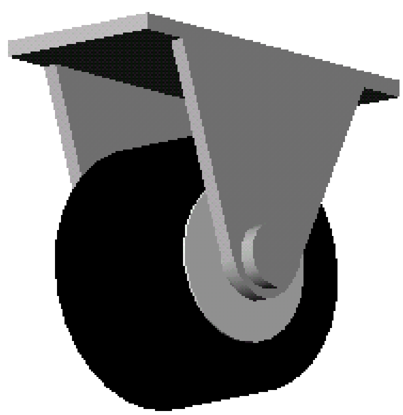


Figure 3: 3-D View of a 2" Diameter Rigid Caster

Figure 4: 3-D View of a 2" Diameter Swivel Caster

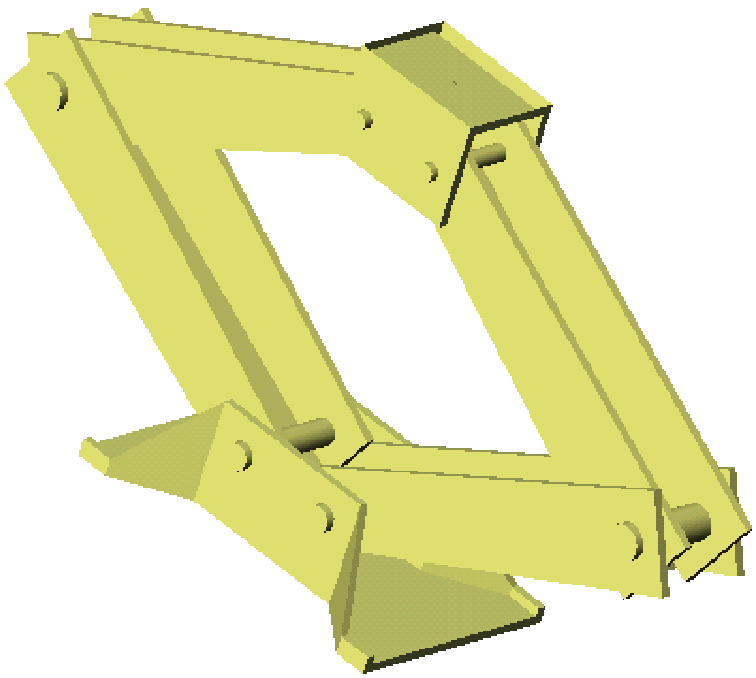


Figure 5: 3-D View of a Typical Scissors Jack (Note: Screw is not Shown)

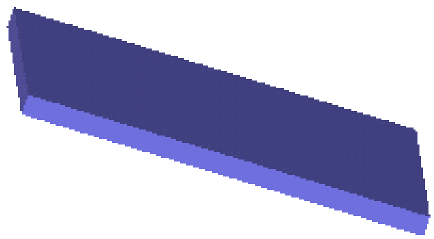


Figure 6: 20” × 15” Acrylic Plastic Platform

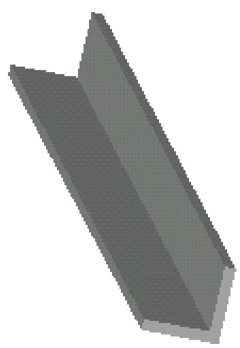


Figure 7: ¾” × ¾” Aluminum Plate

2.4 Structural Analysis

Because of the scaling down of the problem, we will need to build a smaller staircase to simulate the operation of StairCraft. The stairs that we will build will be made of wood and have 8 steps. Each step will have a height of 3 inches, a depth of 6 inches, and a width of 2 feet. We will make these steps to be the solid type and straight edged. At the end if there is time remaining before the deliverable due date, we will make and simulate on other types of steps. In particular, we will try on those hollow steps with only the top edge and no falling edge, steps with the top edges slightly sticking outwards, and/or steps with a curved surface on the falling edge. Figure 8 and Figure 9 show the tentative positions of the sensors mounted vertically and horizontally on the plates. Note the imaginative preset sensing range (in gray lines) of the sensors based on the 12° sensing angle given from the specification indicates that the signals will not be blocked by the structure of the StairCraft itself. Figure 10 shows the sensing ranges of both of the vertical and horizontal sensors used for each of the four legs. StairCraft should be able to bypass any simulation steps with heights ranging from 0 to 3.5" or equivalently from 0 to 7" in real life. In order to make StairCraft bypass even higher heights such as making the device capable of climbing the steps onto buses, we believe more sensors can be used by carefully determining the position of the sensors to solve the problem. Although we will not be implementing this advanced feature in the short run, it is worthwhile to note that StairCraft is expandable to such applications based on our design and approach.

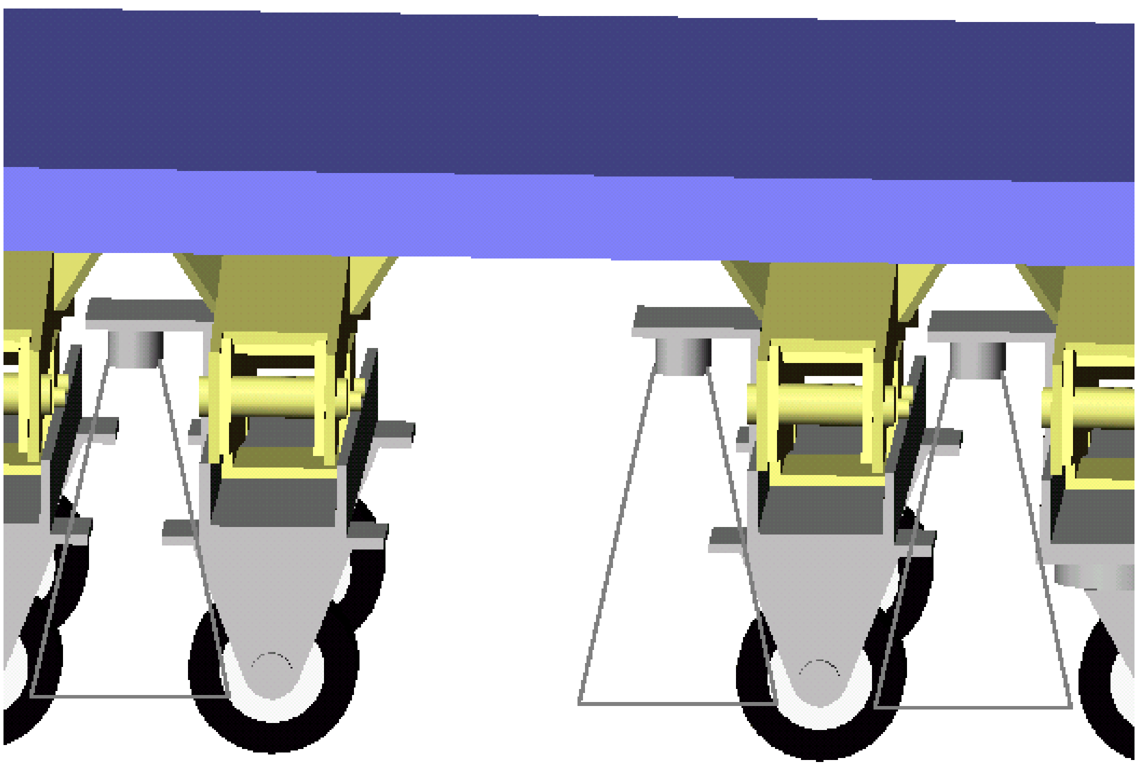


Figure 8: Clearance of Sensing Range of Vertical Sensors

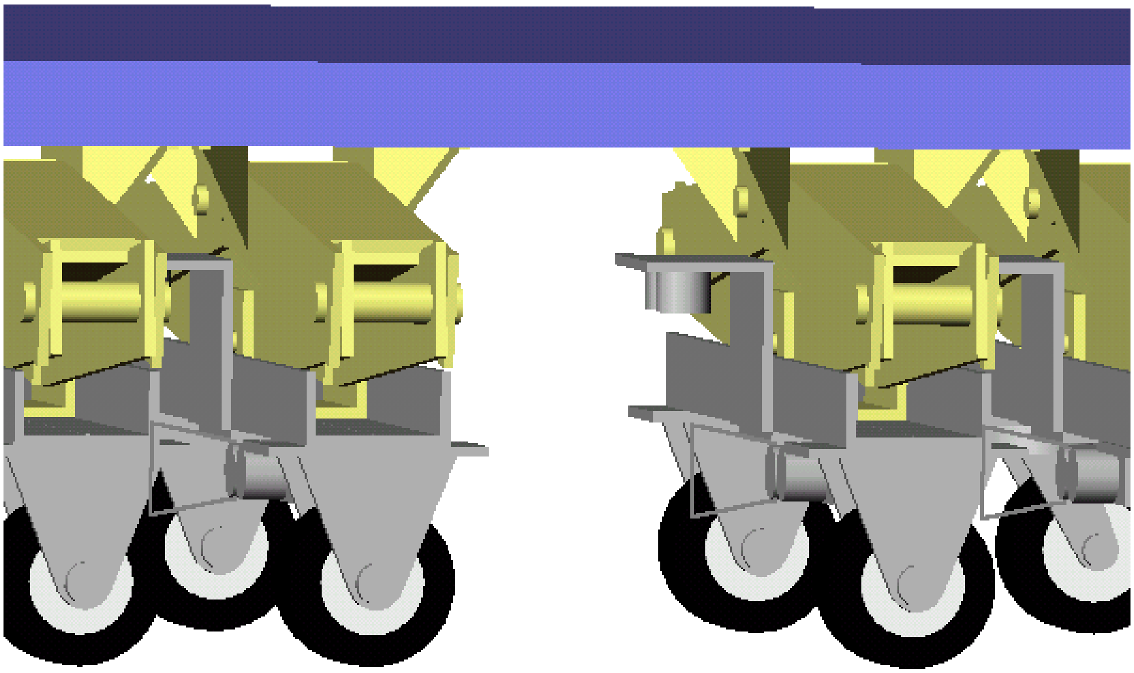


Figure 9: Clearance of Sensing Range of Horizontal Sensors

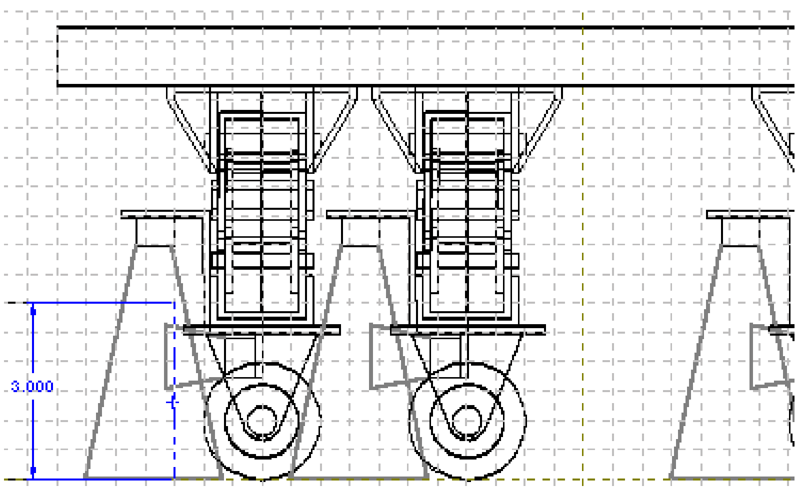
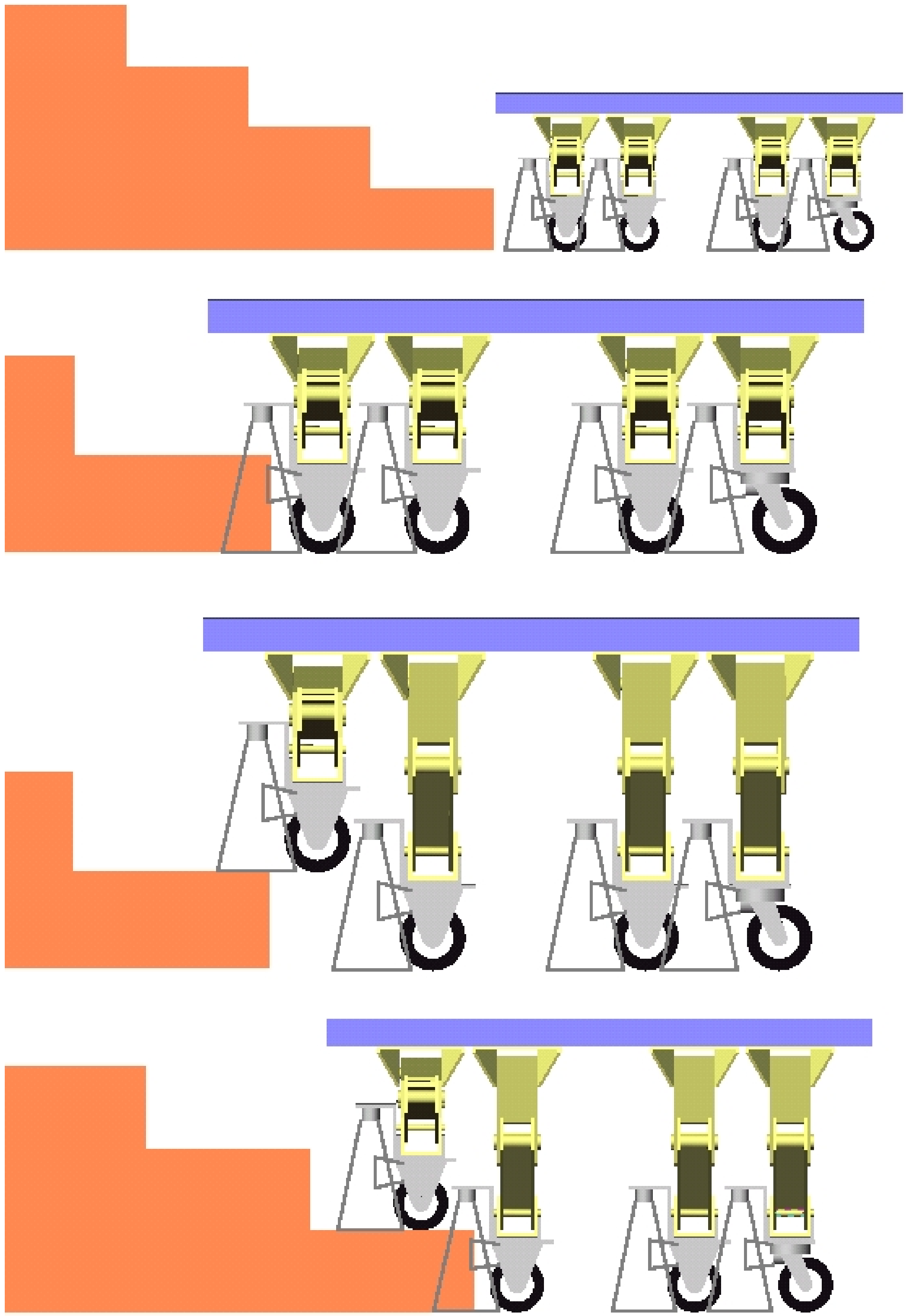


Figure 10: Estimation of Sensing Ranges in Operation

2.5 Sequence of Operation

In the following two pages, Figure 11 highlights a series of snap shots when StairCraft is in operation on a typical staircase at subsequent and consecutive steps. If all the steps are identical on the staircase, it is obvious that the processes and logic merely repeat over and over again until the topmost stair is reached. Intuitively, more than half of the total length of the platform is always supported by at least two of the four supports with at least one support at each end. Assuming the center of mass of the operative load is close to the center of the platform, the system should be statically stable. Only the high level conceptual analysis is included in this design specification, the entire lengthy static and dynamic analysis of the system will be provided upon request.



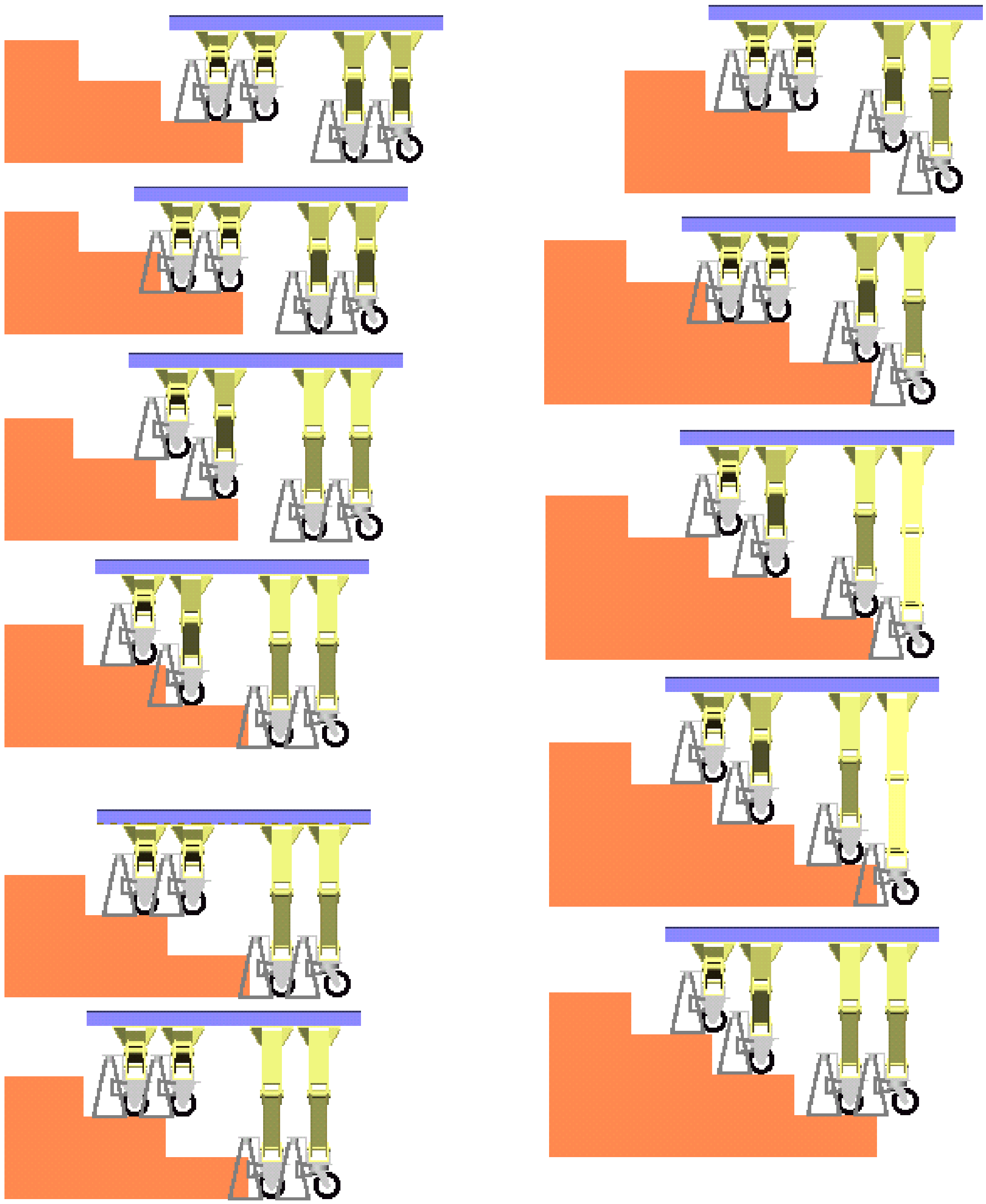


Figure 11: StairCraft in operation

3 Sensors, Controllers, and Acutators

3.1 Sensor Selection

The major requirements for the sensors to be used in StairCraft are:

- Have large sensing range: 1ft minimum
- Light weighted (less than 0.2oz) and small in size (smaller than 1” × 1” × 1”)
- No direct contact to the targets
- Allow some tolerance to the angle of signal impact (at least ±10°)
- High sensitivity (at least ±1.0%)

After comparing several types of sensors and their prices, we have decided to implement our product with ultrasonic sensors. The ultrasonic sensors we chose meet all the requirements mentioned above, and they are inexpensive ($10 for each package: transmitter + receiver).

To construct StairCraft, we need 4 sets of ultrasonic sensors mounted at the bottom of the four legs. The transmitter and receiver will be placed apart by ½” ~ 1” but no more than 1.5” in order to minimize signal interference (the forward and reflected signals) while maintaining desirable sensing range. The transmitter and receiver are directly connected to the sensor input conditioning circuit (discussed in Section 3.2).

3.2 Sensor Input Conditioning Circuit

The sensor input conditioning circuit consists of a 40kHz oscillator to drive the ultrasonic transmitter, and an AC amplifier, 40kHz filter, full-wave rectifier, low-pass filter, voltage amplifier and buffer to condition the signal collected by the ultrasonic receiver. Figure 12 illustrates the block diagram for the sensor input conditioning circuit.

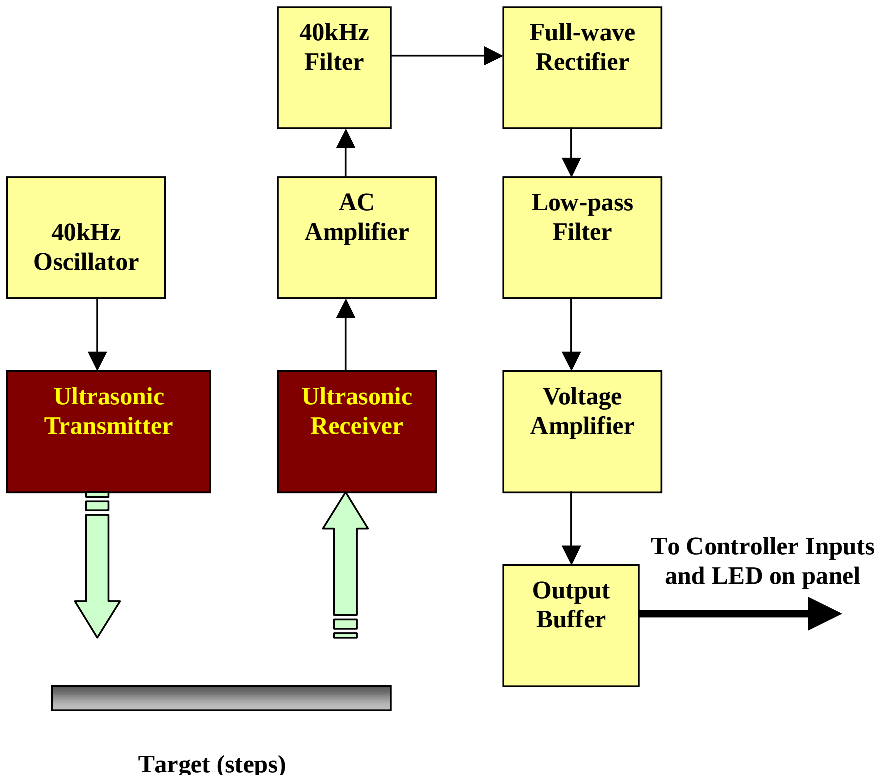


Figure 12: Block Diagram for the Sensory Circuit

Overall, the sensor should give a DC voltage of 5V when an object is present about 0.5' away, and 0V when no object is present. The conditioned sensor input will be fed to controller circuit (see the next Section) and the LED output on the user panel. There will be one sensor input conditioning circuit for each set of sensors.

The following sections give a detailed description for each of the building blocks within the sensor input circuitry.

3.2.1 40kHz Oscillator

Function: Ultrasounds have a frequency of 40kHz. Thus, we need to drive the ultrasonic sensor with 40kHz square inputs with peak voltage of 5V.

Design Choice: HC4060 clock/counter

3.2.2 AC Amplifier

Function: The AC amplifier will remove any DC component from the input and at the same time amplify the AC component of the signal.

Design Choice: Figure 13 illustrates the circuit schematic of the AC amplifier.

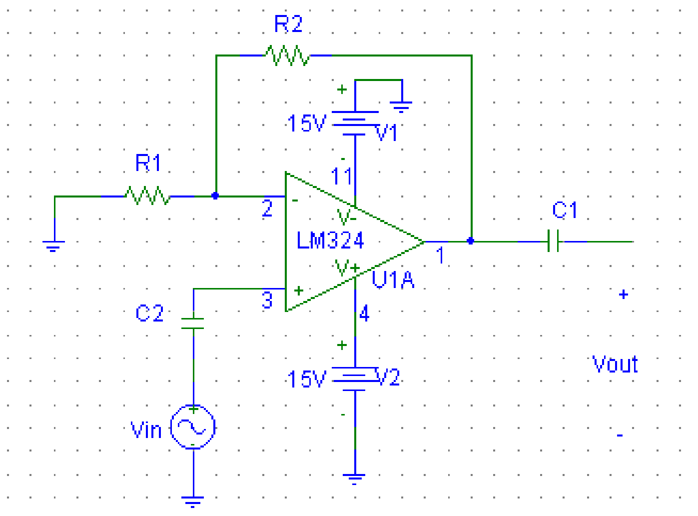


Figure 13: Circuit Schematic of the AC Amplifier

Select the input and output coupling capacitors so that DC component is considerably removed while maintaining fast response. The gain is set based on the selection of R_1 and R_2. We want a gain of 1000 in our design.

$$Gain = 1 + \frac{R_2}{R_1}$$

3.2.3 40kHz Band-pass Filter

Function: To extract the 40kHz ultrasonic signal from the signals (which is a mixture containing other signals in other frequencies) received by the ultrasonic receiver

Design Choice: We use a multiple-feedback band-pass filter as shown in Figure 14.

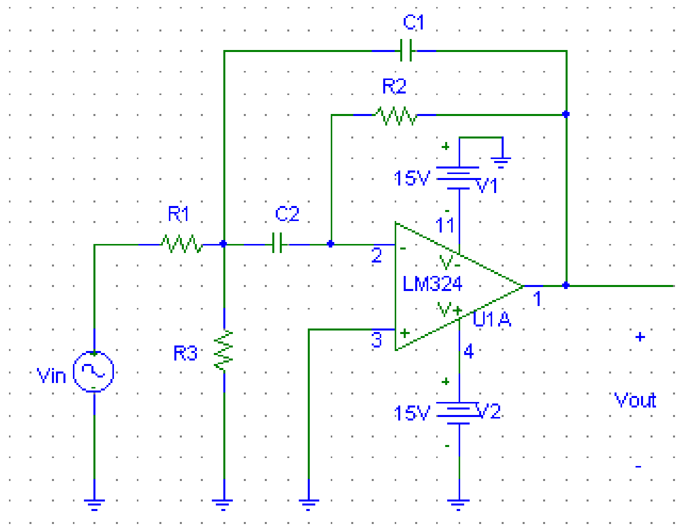


Figure 14: Circuit Schematic of the 40kHz Band-pass Filter

The resonant frequency (f_0) and the quality factor (Q) are defined as:

$$f_0 = \frac{1}{2\pi\sqrt{(R_1 \parallel R_2)R_2C_1C_2}}$$

$$Q = \pi f_0 R_2 C$$

We want f_0 = 40kHz and a high Q.

3.2.4 Full-wave Rectifier

Function: We want to rectify the positive input signals and eliminate the negative input signals. As a result, the output of the rectifier will resemble more like a DC signal.

Design Choice: We use a peak rectifier as shown in Figure 15.

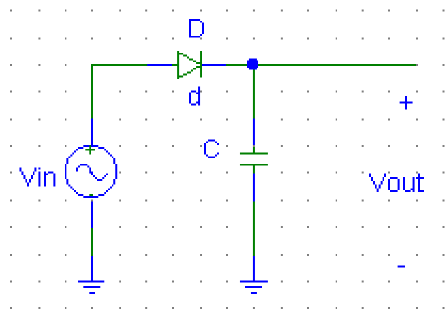


Figure 15: Circuit Schematic of the Full-wave Rectifier

3.2.5 Low-pass Filter

Function: We filter out the high frequency noises from our signal.

Design Choice: We use a RC low-pass filter as shown in Figure 16.

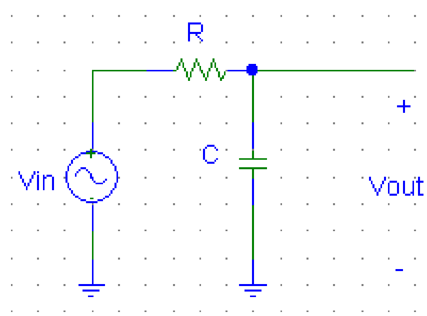


Figure 16: Circuit Schematic of the Low-pass Filter

The time constant (τ) is selected to be 10ms, and can be achieved based on the following equation:

$$\tau = RC$$

3.2.6 Voltage Amplifier

Function: We adjust the output amplitude to between 0V and 5V.

Design Choice: Figure 17 illustrates the circuit schematic of the voltage amplifier.

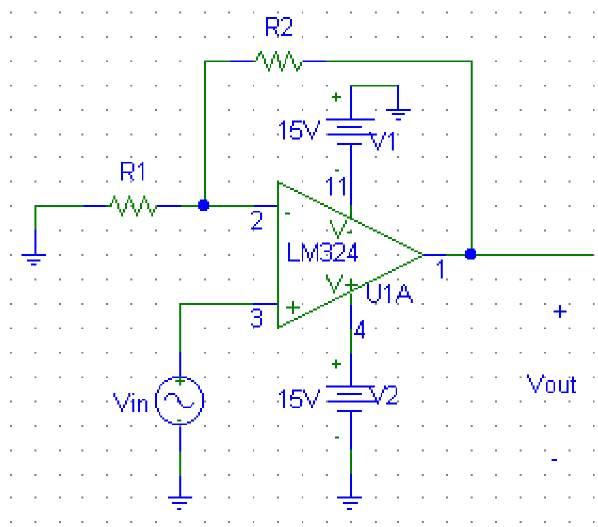


Figure 17: Circuit Schematic of the Voltage Amplifier

The gain can be selected based on the following equation:

$$Gain = 1 + \frac{R_2}{R_1}$$

3.2.7 Output Buffer

Function: To eliminate the loading effect between the sensory circuit and the signal processing circuit (will be discussed in the next section), we put in buffers in between the two stages.

Design Choice: We use an op-amp buffer as shown in Figure 18.

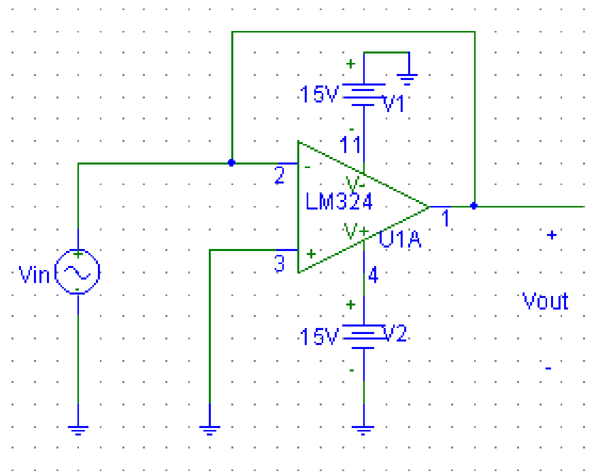


Figure 18: Circuit Schematic of the Output Buffer

3.3 Signal Processing Circuit

Figure 19 illustrates the locations of all sensors and motors in StairCraft.

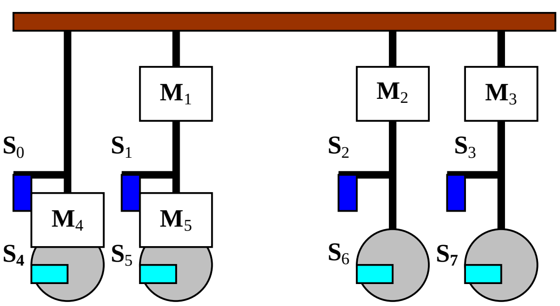


Figure 19: Sensor and Motor Locations in StairCraft

We have decided to use the simplest and cheapest hardware implementation with logic gates to control the climbing sequence of StairCraft over the microcontroller. Also, we will not need to program and do debugging on the code. Sensors S_0, S_1, S_2, S_3 will be mounted on legs 1, 2, 3, and 4 respectively. Sensors S_4, S_5, S_6, S_7 will be mounted on wheels 1, 2, 3, and 4 respectively. Motors M_1, M_2, M_3 will be mounted on legs 2, 3, and 4 to extend and shorten the legs respectively. Motors M_4 and M_5 will be mounted on leg 1 and 2 to drive the StairCraft forward. The control logic of the climbing sequence is as follows:

- If S_0 AND S_4 senses, M_1, M_2, and M_3 drives to extend the 2nd, 3rd, and 4th legs.
- If S_1 AND S_5 senses, M_1 drives to shorten the 2nd leg.
- If S_2 AND S_6 senses, M_2 drives to shorten the 3rd leg.
- If S_3 AND S_7 senses, M_3 drives to shorten the 4th leg.

As shown in Figure 20, the control hardware consists of 11 AND gates and 1 NOR gate. The processed sensor inputs are AND with the user input enable signal, which is the output from the control panel. Therefore, user can start or stop the climbing sequence by pressing the buttons on the control panel. No motors will be activated if the Stop button is pressed. M1s means driving M1 to shorten the second leg. M1L means driving M1 to extend the second leg and etc.

All of the sensor signals are also NOR with the user input enable signal, and the output signal controls the forward-driving motor M_4 and M_5, which drives the first and second set of wheels respectively. Because either the first set of wheel or the second set of wheel would be touching the ground, the forward driving motion is provided any time. We can implement an AND gate with two NAND gates, a NOT gate with 1 NAND gate, and an OR gate with three NAND gates. A four pin OR gate can be implemented with three OR gates. Therefore, we need 32 NAND gates in total. The chip 74HC00 has four NAND gates per ship. We will need to use at least eight of this chip in our design.

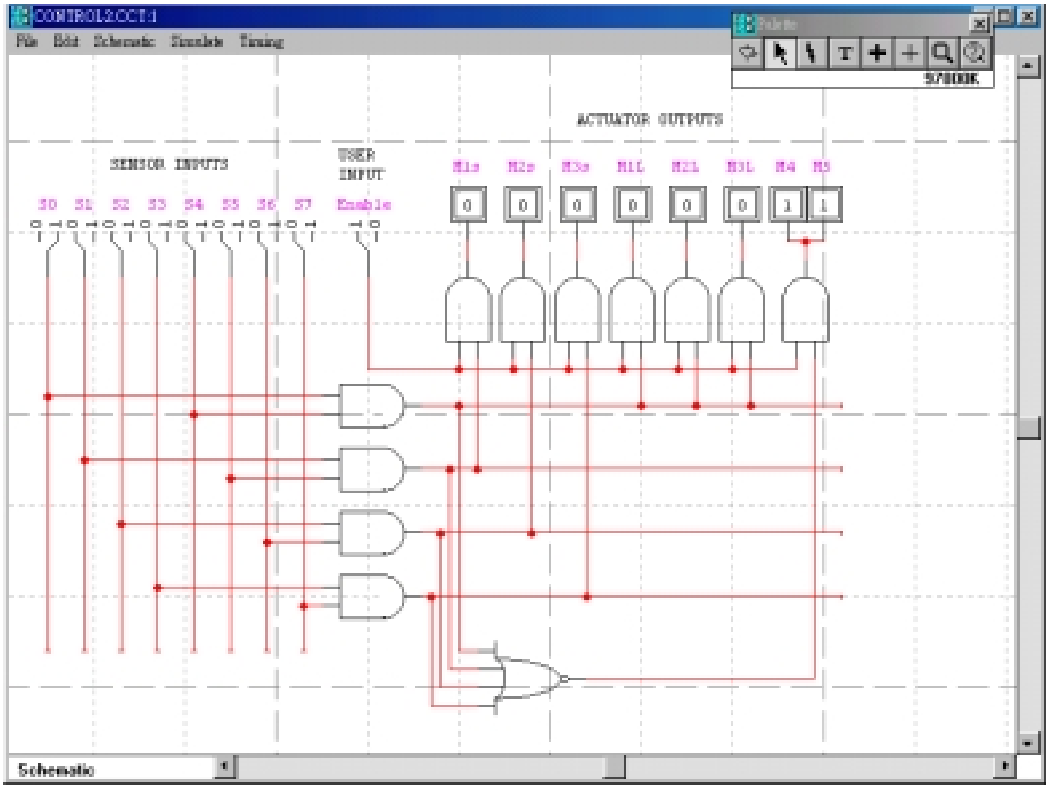


Figure 20: The Climbing Sequence Control Hardware.

3.4 Motor Drive Circuit

The digital output from the processing circuitry will be used to turn on and off both the lifting motors (stretch or shorten the legs) and wheel driving motors (move the cart forward. Since the motors need to be able to rotate in both clockwise and counter clockwise directions, we use the H configuration motor drive circuit as shown in Figure 21.

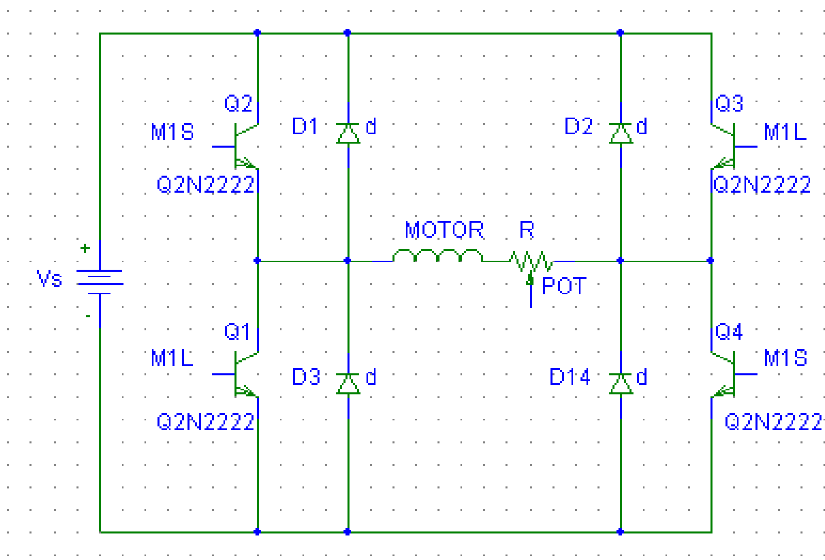


Figure 21: Motor Drive Circuit Schematic

When Q1, Q3 are on and Q2, Q4 are off, current will flow from right to left through the motor. When Q2, Q4 are on and Q1, Q3 are off, current will flow through the motor in the opposite direction and therefore the motor will also rotate in the other direction. For example, to make the first leg longer, the processing unit will send a logic high to the base of Q1, Q3 (via the variable M_{1L}) and a logic low to the base of Q2, Q4 (via the variable M_{1S}). As a result, the motor will rotate to make the leg longer. On the other hand, if the processing circuit makes M_{1L} low and M_{1S} high, the motor will rotate in the other direction and makes the leg shorter.

The pot in series with the motor is used to control the current through the motor. Because we use car jacks to implement the 4 legs of StairCraft, the up-down speed of the jack will be different for the same motor speed. This we implement a pot to measure the angle how much the jack has stretched up and use the pot resistance value (which depends on the car jack angle) to control the current so that the upward speed for the jacks are constant.

There will be one motor drive circuit for each motor.

4 User Interface

The user interface of StairCraft is a wired control pad of the size that can be held by the user with one hand and operate the control buttons with another. The controls on the control pad consist of:

- A power On/Off switch.
- A Start/Stop switch.
- Four Sensor Status LED's.

5 Conclusion

The detail implementation of the StairCraft has been discussed in this documentation. At the time of publishing, this particular approach has yielded favourable results. The approach not only benefits from simpler and more efficient design, but also the financial pressure release. We are confident that we have chosen the most efficient and most effective method by which to solve the problem of automatic electronic stair travelling device. Moreover, we believe that our system will cost very little, which will give us an edge over other similar products in this not-yet-developed market.

Though this project was originally intended to be for a school course only, we feel that this system will work well enough that it will be marketable in the real world. The potential of StairCraft is not limited in helping the physically challenged people. It can also be applied in different applications such as cargo lifting for heavy-duty industry or furniture moving for home moving business. Besides the valuable experiences we get in the developing process, we can bring our product to the market and let people experience the power and convenience Beyond the Horizon provides.

