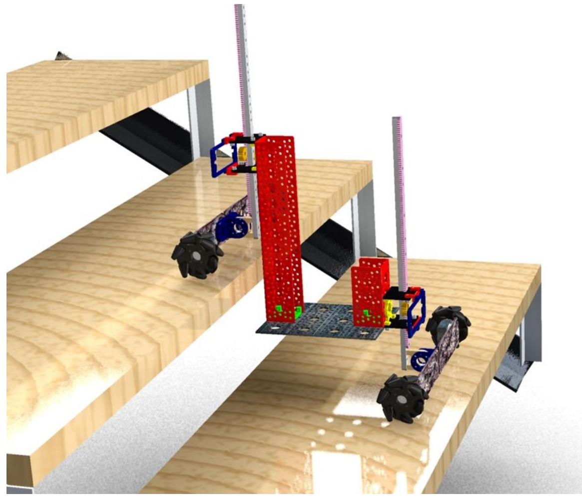
ME 463: Stair-Cleaning Robot
Final Design Review Report

Team:	Nimbus 2000
Members:	Yiming Ding
	Jiayun Shao
	Yuchen Zhang
	Liu Hong
Instructor:	Eric Nauman



05/02/2016

Executive Summary

The purpose of this project is to design an automatic housekeeping robot that can clean the standard stairs in houses and buildings. The robot is mainly comprised of climbing components that land itself onto the next step, and cleaning components that collect both small and large particles on different surfaces. The climbing components include two pair of mecanum wheels that enable the robot to move forward and laterally without turning its body. Each pair of mecanum wheels can be lowered and lifted by a gear and rack system so that the robot can land its wheels and body on the next step. The cleaning components which include a vacuum and two brushes are installed at the bottom of robot. As for the control, Arduino Mega 2560 R3, along with Adafruit Motor Shield v2.3, is used to control DC gearbox motors that drive mecanum wheels, servo motors for gear and rack systems and ultrasonic sensors. Ultrasonic sensors are used to detect robot's position against the edge of stairs and the side wall. A 9V battery is used to power all elements just mentioned. In addition, another 9V battery is connected in an outer circuit with transistors to separately provide power for the cleaning components.

To ensure proper and safe operation, tipping detection code is embedded into the Arduino with the help of ultrasonic sensors. Once tipping is detected, power is cut down for the robot to limit damage. LED light is working as part of the warning system, along with the noise from motors, to alert people around that the robot is working. There is also an emergency switch on the top to stop the robot completely in extreme cases.

The final design of the stair-cleaning robot can move 3 inch per second on the stairs, and it takes approximately 30 seconds to climb down one step. During the testing, failure can happen when climbing down stairs and the success rate is 90% for the first ten attempts after

new batteries are used. Success rate decreases with larger number of attempts and drops rapidly after 24 attempts, as the robot is running out of power. Torque on all motors are decreased, and ultrasonic sensors start to fail. The robot can collect approximately 80% of dirt after one cleaning cycle. This number can be improved by sweeping more cycles or using a more powerful vacuum. The robot is limited to be incapable of cleaning the edges, but implementing rotating brushes on the side may help solve this problem. In conclusion, it is promising to bring this stair-cleaning robot, which cost a total of $589 during the development period, into market if the further improvements are made.

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Problem Definition

There are urgent needs asking for an automatic machine to free people, especially housewives, from the tiredness of cleaning dirty stairs. Based on benchmark research, current products can either clean the flat floor automatically, or provide with supplemental tools in the cleaning process. However, none of them has fully solved the problem, and that motivated Nimbus 2000 to work on this project and come up with a design that can provide a fast, safe, automatic and reliable cleaning system for dirty stairs.

The project intends to design an automatic robot that can clean the standard stairs in house and buildings. The robot will only go down stairs and sweep the top surface of each step. The robot should be able to deal with different kind of surfaces such as carpet and hard wooden floors, and may also clean the front surface of stairs after implementing additional brushes. It is also necessary for the robot to avoid tipping hazard in climbing stairs.

The size of the standard stairs is defined by three dimensions: rise, run and tread (Shown in Figure 1). According to Council of American Building Officials (CABO), unit run should be at least 10 inch and unit rise should not exceed 7¾ inch. The average tread is from 2 feet and 8 inch to 3 feet and 6 inch [1]. The stair-cleaning robot will be mostly working on stairs which have unit run from 12 inch to 18 inch, unit rise up to 7¾ inch and unit tread from 2 feet and 8 inch to 3 feet and 6 inch.

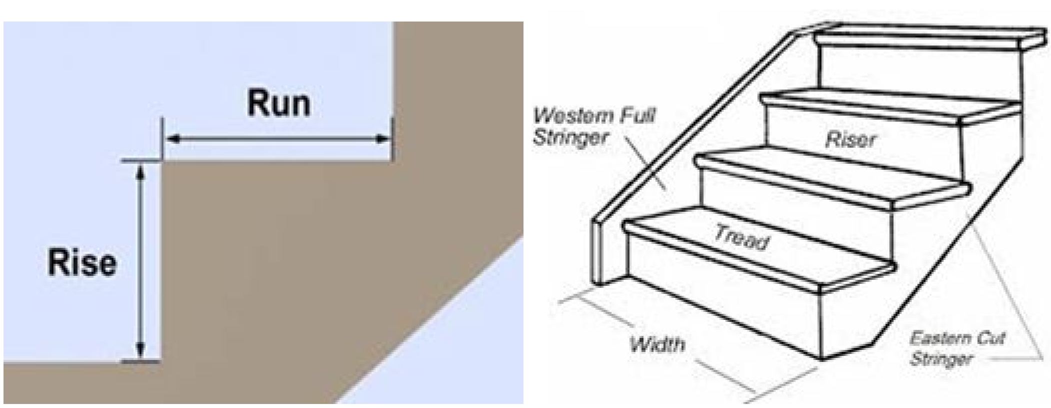

Figure 1: Diagram of standard stairs

The challenges of the problem include the complicated three-dimensional geometry of stairs compare to flat ground, combination of cleaning and climbing mechanism, insensitivity and tolerance for small geometry uncertainties.

The target customers for Nimbus 2000 are people who have to clean stairs frequently, like housewives and cleaners of a building. Usually they spend a lot of time to clean the stairs because there is no automatic machine which can help them. The stairs have many blind angles and edges, meaning that it would require more time than cleaning the same area of the flat floor. It usually takes 2-5 minutes per stair to be fully cleaned. If you don't want to waste your time, hiring someone is a good option. However, it could be super expensive. Usually, it is $3 per stair plus the labor fee [2]. Also, as we all know, cleaning stairs can be painful because it may cause back injuries in some extreme cases.

There are several cleaning products in the current market that can help users to clean the flat floor or stairs:

●Vacuum robot (iRobot Roomba 650, $375)

The product is shaped like a disc with a diameter of 13.39 inches and weighs 7.9 lb. The robot applies a spinning side brush to clean along wall edges, a counter-rotating brush to pick up dirt, dust debris and hairs from the floor, and a vacuum to suck the dirt and hair of the brush into the bin. The robot can clean the carpets, tile and hardwood floors, but not for stairs.

●Mopping robot (iRobot Braava 380t, $255)

The product is mainly for mopping hard-surface floors, featuring a pro-clean system, and cube-to-cube navigation system. The product is rectangular shaped with a dimension of 3 x 8.5 inches and weighs 4 lb. Similar to Roomba 650, this mopping robot cannot be applied to stairs.

●Handhold cleaning equipment

Besom, electric vacuum cleaner, and duster cloth, those methods can only assist instead of undertaking the cleaning process automatically, the efficiency is dependent on human labor.

From the research results above, the vacuum robot and the mopping robot are good solution for flat floor cleaning, but they cannot be applied on stairs. The Handhold cleaning equipment can be applied on stairs cleaning. Unfortunately, it still requires human labor. Therefore, none of existing products are perfect for stairs cleaning. There is great potential for the stairs cleaning robot to prevail in the current market.

The design criteria for evaluating the success of the project are defined as follows:

●Cleanliness

The most important requirement for a cleaning robot is cleanliness. It should able to clean more than 99% of dirt including hair, small particles and other dirt. Also, the robot should be able to clean blind angle and edges.

●Speed

Typically, the tread of the stair is around 3 feet and 6 inch. The robot should be able to clean more than 30 steps per hour.

●Lifetime

This robot should be able to work more than 3 years.

●Energy-saving

It should be able to work for 5 hour per charge if a rechargeable battery is used. If there is problem to find the suitable battery, power cord can be used instead.

●Reliability and Stability

Safety is the most important part Nimbus 2000 focus on. This robot should not have any tipping hazard. Warning system will be added in order to warn people around.

●Work for multi-surface

The robot should be able to clean wooden, carpeted and tile.

●Applicable for stairs with different rise

The rise is different from stairs to stairs. Based on the council of American Building officials, the unit rises should be less than 7.75 inches. Therefore, the robot should be able to be applied to different rise in that range.

●Costless

The cost for developing the robot should be around $500.

●Easy to clean itself

The way to clean the robot itself should be easy. All dirt will be collect to a box and users only need to open that box and clean the dirt inside.

Design Solution

Mechanical Parts

The final design of the stairs cleaning robot include both hardware and software solutions. For hardware, or mechanical parts, of the robot, the main body is assembled from aluminum brackets channels and board purchased from ServoCity. The cleaning components and two free turning wheels are located underneath the main platform. The electronic components are fixed on the top of the aluminum board.

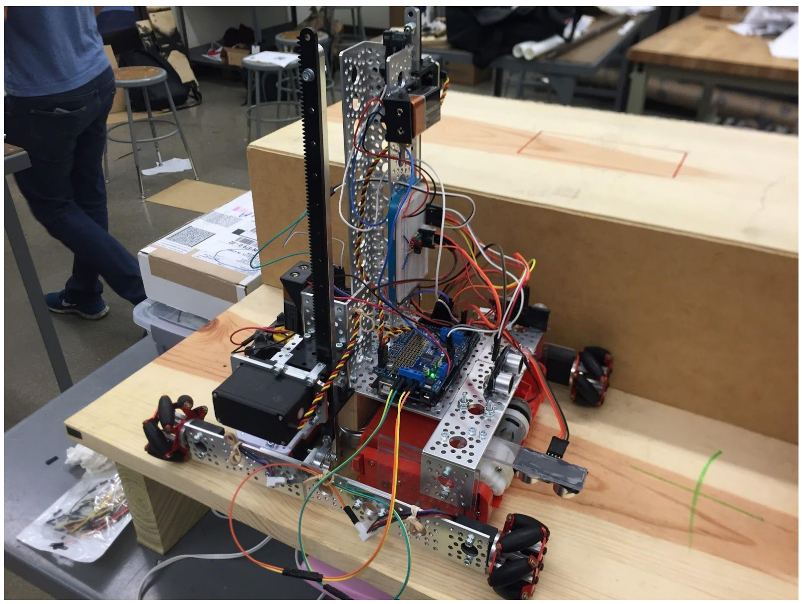

Figure 2: Final design of the stairs cleaning robot

The main body has the function of moving the robot along the steps and landing it on the next step. There are two gear and rack systems at the front and back of the robot, which are driven by the HS-785HB servo motors attached on both of them. The front servo motor is fixed at the bottom of the aluminum bracket channel while the back servo motor is at the top, because the front gear/rack system will lower the wheels down but the back one will lift the wheels up. The four mecanum wheels are purchased from Sparkfun and mate directly with the DC gearbox motors. Enclosures of the four motors are fixed on the aluminum boards, and the four long boards are attached to the racks. Further information can be obtained from the CAD drawings in Appendix 2. Therefore, the four wheels support the whole weight of the robot and can move vertically under the demand of Arduino. The four wheels are mecanum wheels that can enable the robot to move both forward and laterally without turning its main body. Figure 3 shows how the robot moves when mecanum wheels rotate in different directions. When all the wheels rotate forwards or backwards, the robot will move forwards or backwards. When the left wheels rotate inwards, and the right wheels rotate outwards, the robot will move to the left. When the right wheels rotate inwards, and the left wheels rotate outwards, the robot will move to the right.

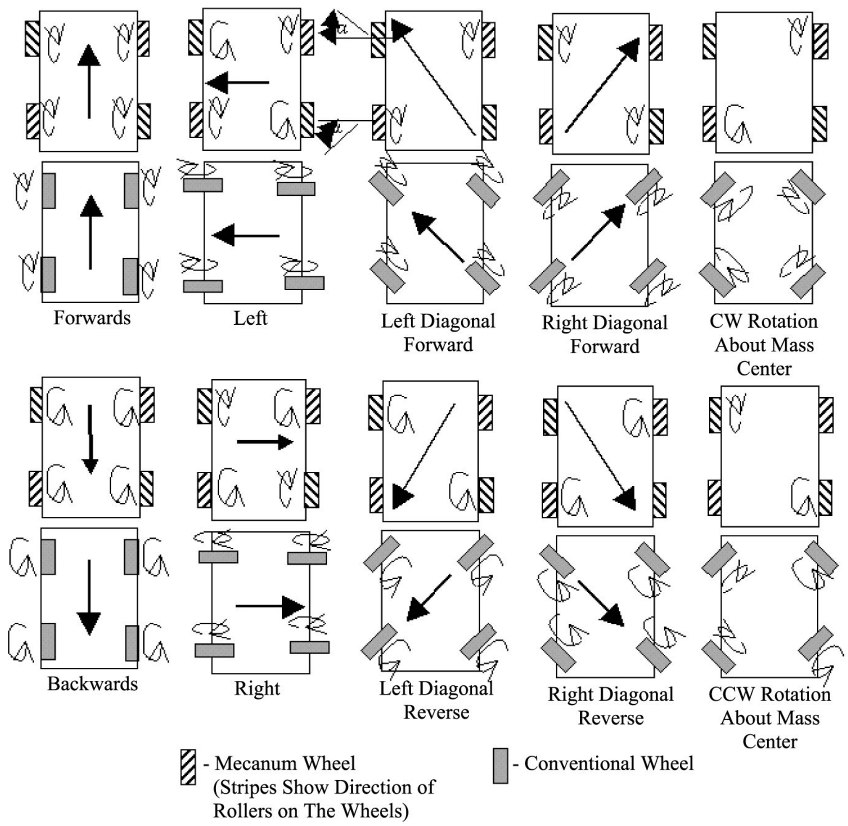

Figure 3: Principle of Mecanum wheels

To drive the four mecanum wheels, four DC gearmotor with encode are connected to the wheels. The mecanum wheels include 7 mini roller which is 45 degree contact with ground. Basically, the robot can move in any direction with the help of mecanum wheels. If the left side pair of mecanum wheels rotate toward inside and the right side pair of mecanum wheels rotate toward outside, the robot can move to left. On the contrary, if left side rotate toward outside and right side rotate toward inside, the robot can move to right. During the lowering process, all mecanum rotate same in same direction to drive robot forward.

Underneath the main platform of the robot are brushes, vacuum and two free turning wheels. The vacuum is at the left side of the robot and the brushes are at the right side of the robot, with the two free turning wheels at the middle. The brushes and vacuum are disassembled from an old cleaning robot Nimbus 2000 purchased on Ebay. The free turning wheels are picked from the Sherwood Lab. However, the original brush box and vacuum box are too large for the robot and the step size. One part in the middle of the brush box has already been removed by using bandsaw and the bush box is then glued together. The edges of the vacuum box are polished so that it can be placed underneath the robot. The brushes and vacuum are attached to the main body of the robot by using plastic board and screws. The bushes are powered by a motor and a set of gears on the side of the box. The vacuum vent where the dirt are collected is at the back side of the vacuum box and the collected dirt is stored inside the vacuum box, which can be opened and dumped by the users. The free turning wheels can support the robot body when the other wheels do not land on the stairs. The height of the free turning wheels are critical to the robot because when the free turning wheels are too long, the mecanum wheels will lose the touch with the stairs, and can no longer move the robot.

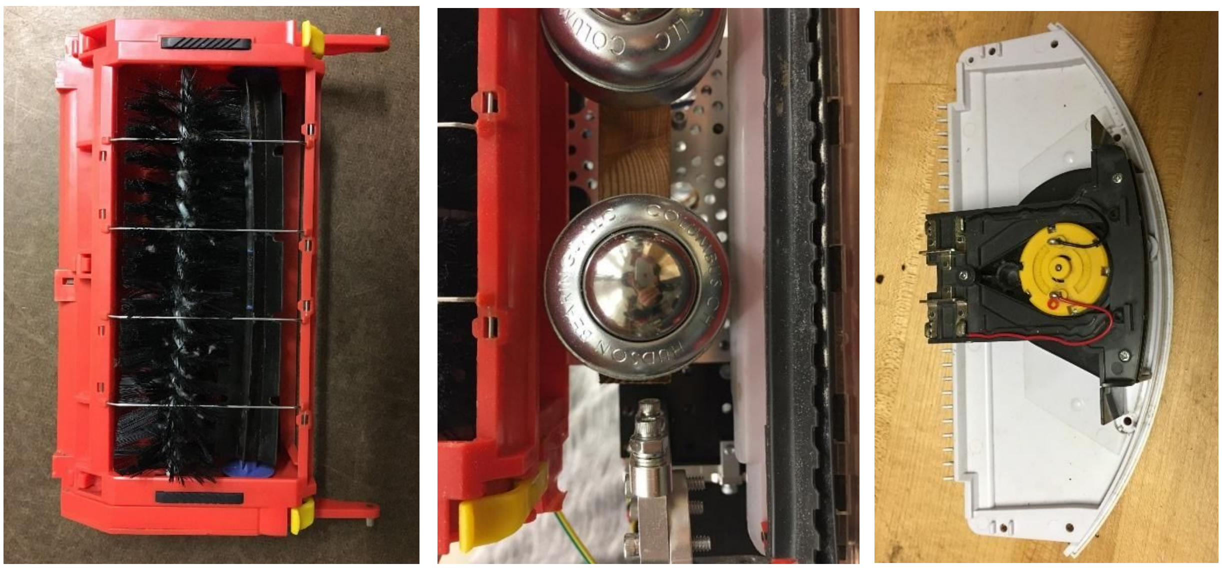

Figure 4: Brush box (left), free turning wheel (middle), vacuum box(right)

The motor and gears for the brushes are located at the side of the box, the vacuum vent is at the back side of the box. The dirt collected from the vacuum are stored in the vacuum box.

Power and Control

Arduino Mega 2560 R3 with Adafruit Motor Shield v2.3 are used as the microcontroller of the stair-cleaning robot. The motor shield is stacked onto the Arduino, using up the 17 pins on the left half side, and it has a capacity to control 2 servos and 4 DC motors. It can provide a higher current than the digital channel on Arduino and coding is much easier with the help of Adafruit library. The rest 47 pins on the Arduino Mega can be used for the ultrasonic sensors, switch, emergency stop and the input channel for the transistor, which will be explained later. All these elements are powered by a Energizer 9V battery.

In pre-testing of the motors for the brushes and vacuum, it is discovered that these cleaning components require a much higher current (around 0.4A with no load) than other motors, which far exceeds the current capacity of the microcontroller. Therefore, a outer circuit powered by another 9V battery is developed, using NPN 3074 transistors, to both turn on/off the two motors and ensure safe operation.

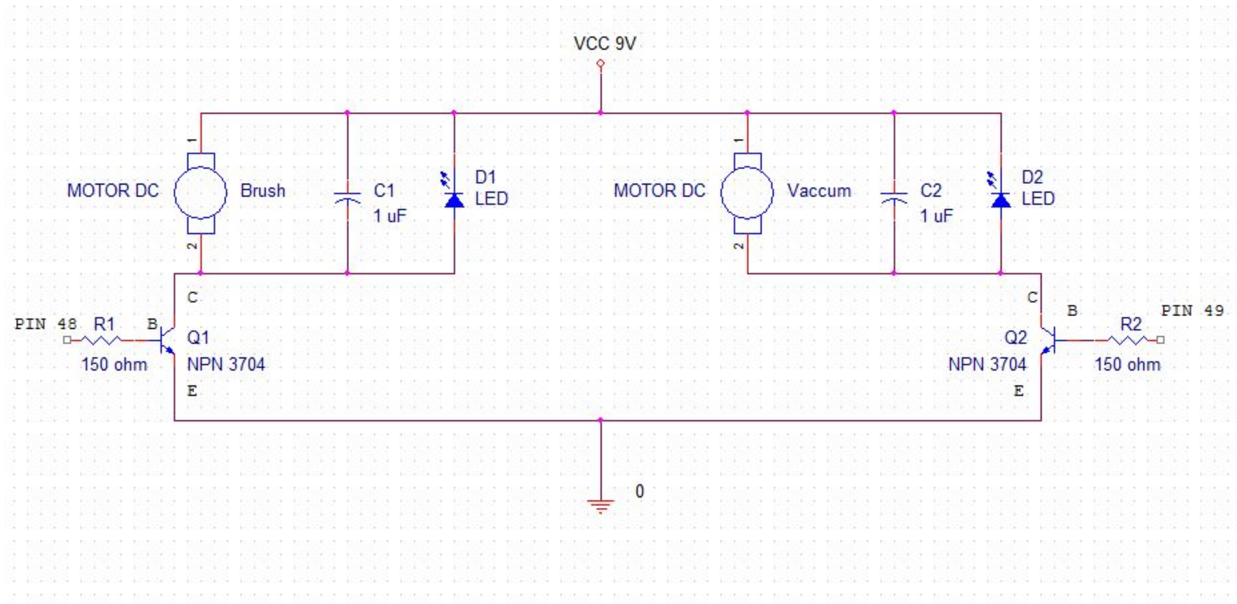

Figure 5: Circuit for LED warning system and cleaning section

As is shown in the circuit drawing above, the two motors are in parallel with a capacitor and a LED, with one end connected to 9V and the other end to the C end of the transistor. The E end of the transistor is grounded, and B end is wired to the digital output pin on Arduino. When the output states on Arduino pin 48 and 49 are set to be “HIGH”, the transistor will abridge the C and E end, applying the 9V voltage difference on the motor and turning it on.If the output state is set to be “LOW”, the circuit is acting similar to a open circuit and the motors are turned off.

As mentioned before, Adafruit library is implemented to help with the control of the DC motors and servos. The four commands used to control the DC motors are “run(FORWARD)”, “run(BACKWARD)”, “run(RELEASE)” and “setSpeed()”. The first two commands control the rotating direction of the shaft on motors, and the exact direction depends on the configuration of installing the motors and require testing to figure out. The third command cancels any voltage acting on the motor, and therefore “release” any rotation and make it a free-turning wheel. The last command actually controls the value of voltage applying on the motor. Choosable value ranges from 0 to 255, and if the 9V battery is used, 0 represents 0V and 255 represents 9V, and the exact angular speed can be referred from the specification sheet provided by Servocity.

The two servos are controlled with PWM signal and the command used is "writeMicroseconds()". The correlation between the input value and the exact location is determined from pre-testing, and in real application, four pre-set values are determined in advance and set in code for stair with certain value of rise.

The application of ultrasonic sensor is critical to proper operation of the stair-cleaning robot, as only an accurate feedback on the location of the robot can ensure safety. A total of four ultrasonic sensors are installed into the robot. One is attached on the right side of the robot, facing rightwards, and this one provides with distance to the side wall. Two sensors are fixed on the centerline of the mecanum wheels, one for front and one for back. Both of them face downwards so that the rapid change in detected distance as the robot moves forward lets the microcontroller know that the front/back wheels are in the air and can be lowered to the next step. The last one is glued on the back of the robot and faces backwards. Combined with the first sensor, the position of the robot can be determined at any time during operation.

Before operating the stair-cleaning robot, there are a few prerequisites for the users: the user should be aware of the number of their stairs and type it in the User Interface (which is the Arduino IDE program during preliminary development) as user inputs; the user will have to remove all large particles, such as stones or baby toys, from the stairs; for best cleaning performance, the user needs to place the robot at the left bottom corner on the first stage, facing towards the down side of the stairs, as is shown in the following figure.

Figure 6: Robot placement configuration

After the robot is powered on, the robot will ask for the user inputs about the stairs and wait until the user finishes all the prerequisites. It will change into the cleaning state after the user pushes the "Start Cleaning" button, as is shown in the flowchart below.

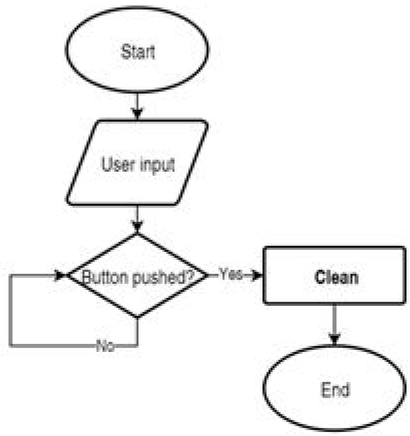

Figure 7: Flow chart in the preparation state

In the cleaning state, the robot will first do a position calibration with the ultrasonic sensor on the front wheels, facing downwards. The robot will move forwards until a distance change is detected by the ultrasonic sensor (ideally increased by the rise of the stairs), and the location of the front edge is determined. Then it will move backwards to the back edge of the stairs, and do one sweeping cycle by moving from the left end to the right end, during which the cleaning components attached to the bottom of the robot will be turned on, and do the cleaning job. After the robot has moved back to the original position (left end), two conditions will be checked by the control system in sequence. First, the control system will check whether if the whole area on the current stage is cleaned, in other words, the robot has gone through all area of the stage. If not, the robot will move forwards some distance, which is determined by the embedded algorithm, and do another sweeping cycle. If yes, the control system will check whether if the robot has cleaning all the stairs, in other words, is the number of stairs equal to the times it has climbed down. If yes, the robot will stop working, and wait for the user to pick it up. If not, it will change into the climbing state.

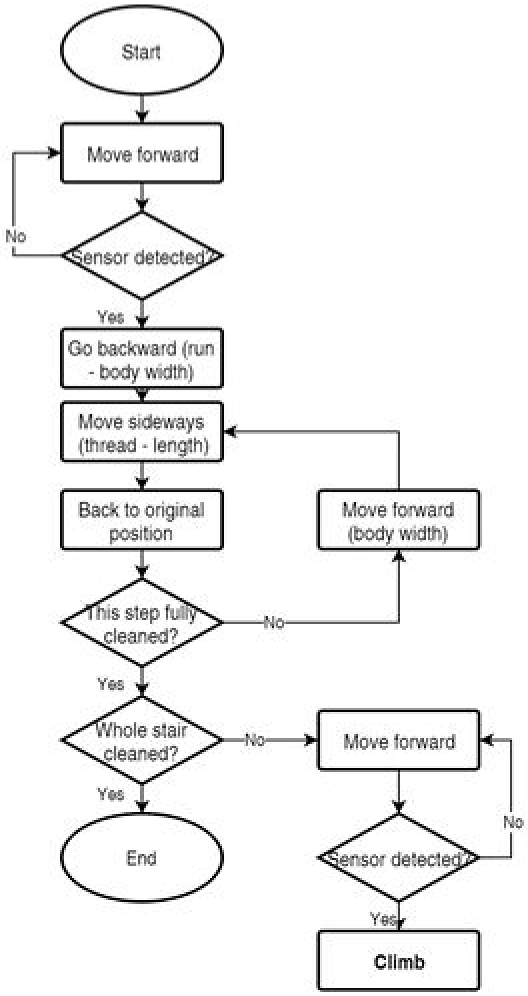

Figure 8: Flow chart in the climbing state

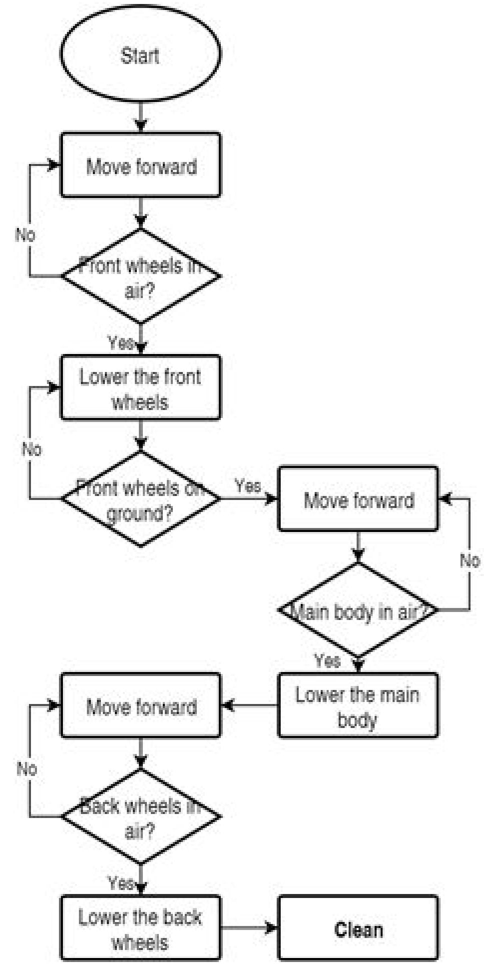

Figure 9: Flow chart in the cleaning state

During the climbing state, the robot will climb down to the next stage via lowering different parts of itself in sequence. It will first move forward until it is able to lower its front wheels to the next stage via angular control on the front servo motor. Then, with four wheels supporting the robot, two on the next stage and two on the current stage, it will move forward until its whole main body is on the air. By controlling both servo motors, the main body of the robot will be lowered onto the next stage, and thus the robot will be able to stand with the front wheels as well as the free-turning wheels at the bottom. Similarly, it will move forward and lower its back wheels, and the whole ”Climbing Down” process is finished, after which the robot will change back to the cleaning state.

By iterating the “Cleaning - Climbing” process, the stair-cleaning robot is capable of integrating the climbing and cleaning mechanism and thus achieving the primary goal of automatic stairs cleaning for standard stairs.

The Warning system is an important system for safety consideration. Embed code is able to detect the tipping by the ultrasonic sensor which is located at the front bottom of the robot. The distance detected by the ultrasonic sensor should range from 3 cm to the rise of the stairs, and change smoothly along with angular control of the servomotor. When rapid change in the distance detection is observed, the system will know that the robot is tipping and cut out power immediately, which will limit the possible damage to the minimum. Also, lights warning, which is the LED light in parallel with the brush and vacuum motors as is shown in the figure below, will be turned on when the robot is running. Therefore, people will know there is a robot in operation.

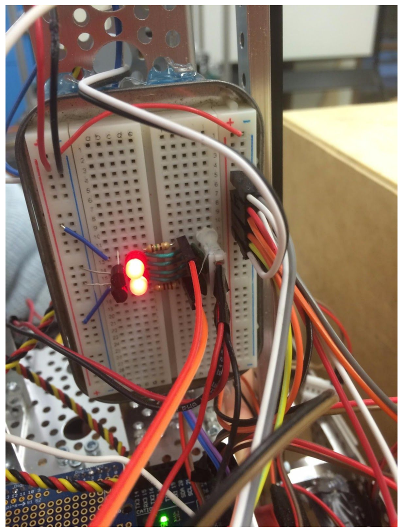

Figure 10: Real circuit for LED warning system and cleaning section

Prototype vs. Final Design

Considering safety issues, Nimbus 2000 never tests the stair-cleaning robot on real stairs but builds a set of 2-step wooden stairs themselves especially for the testing, which can be seen in Figure 2 below the robot. The stairs have unit run of 11.5 inches, unit rise of 6¾ inches and unit tread of 16 inches, which all lie into the range of standard stairs.

The prototype doesn't ask the user for input of the number of stairs since only 2 steps of stairs is available. The robot only sweeps from the left to the right once on each step, as the size of the prototype is similar to the unit run of the wooden stairs, and only one cleaning cycle covers the whole top surface.

The prototype is launched by pressing the start button on the top of the robot, and 10 seconds is given to let the robot finish the pre-settings on all elements, such as the default position of the servo motors, setting input/output state for Arduino digital pins, connecting and opening DC motors. After that, the prototype moves from the left to the right with the cleaning elements turned on, with mecanum wheels rotating in the appropriate directions. When ultrasonic sensor detects the distance to the side wall is 8 cm, the robot will “release” all DC motors and change the direction, so that the robot can go from the right to the left and stop at the original position, which is determined by the same ultrasonic sensor.

Then, the robot is ready to climb down to the next step. As is shown in following figures, the robot moves forward, and lower its front wheels. With its main body in the air, it moves forward and lower the main body. Now the majority of robot is landing on the next step and it moves forward and lower its back wheels. The climbing mechanism is no different from the one in final design, so is the warning system.

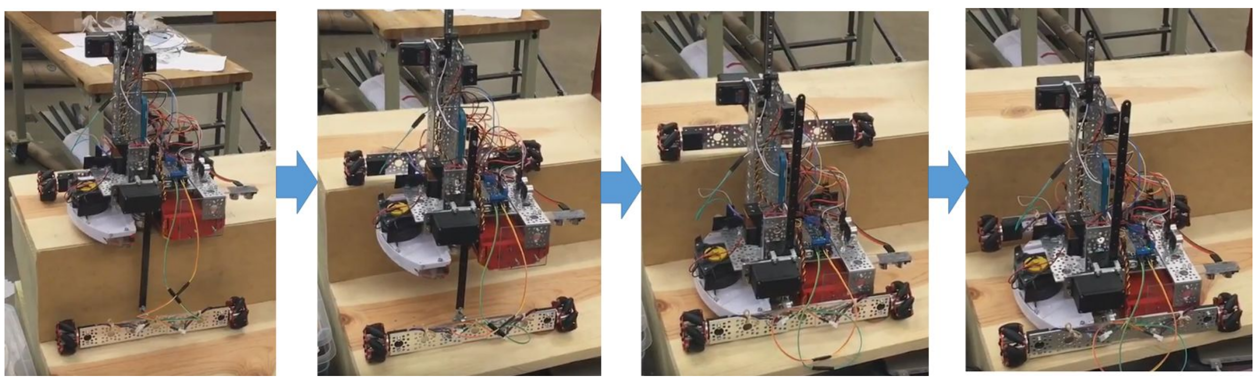

Figure 11: Pictures of stair-cleaning robot climbing down stairs

Comparison to Benchmarks

Compared to the commercial cleaning robot in the market, the robot is innovative for combining the cleaning mechanism with the climbing mechanism, and therefore solving the gap between the need to cleaning stairs automatically and the lack of effective tools. However, this robot is not equipped with sophisticated navigation system that enable the robot to avoid obstacles and return to the base to recharge, like other sweeping robots do. Besides, the cleaning components are also in poor condition as they are disassembled from very old cleaning machine, and that results into the “not good enough” cleaning results, which will be discussed in later chapters.

If our moving mechanism can be implemented into the current commercial robot, the robot will be able to not only clean the stairs but also able to clean areas at different floors in one house. This will save a lot time for the customers because they don’t need to place the cleaning robot at different floors and clean the stairs by hand. Besides, it is also likely that different cleaning methods will be developed for the cleaning robot, such as steaming, mopping, and UV sanitizing. The cleaning components are also easy to disassembled from the robot so that the customer can replace the vacuum or brushes with other cleaning methods according to their needs.

Testing and Validation

Climbing test

Since the 9V battery with high capacity requires to be customized for the stair-cleaning robot, the battery used in the design phase is the 9V battery with 595 mAh capacity which can be found in any supermarket. In order to determine the success rate of climbing as well as calculate the lifetime of the 9V 595 mAh battery, two new 9V Batteries are implemented into the stair-cleaning robot and tests are performed. In each cycle, the robot sweeps once on the top surface and lands itself to the next step. Success or failure is noted down as follows:

Table 1: Success rate of batteries when the robot has done a certain number of steps

(✔: success, ✘: failure)

NO.1-5	✔	✔	✔	✔	✔
NO.6-10	✔	✔	✔	✘	✔
NO.10-15	✔	✔	✔	✔	✘
NO.16-20	✔	✔	✔	✘	✘
NO.21-24	✔	✔	✘	✘	

As is shown above, success rate in the first ten cycles is 90%, but drops to 86.7% in the first fifteen cycles. Around 24 cycles is the maximum number of cycles two brand-new 9V batteries can support, and it indicates a positive correlation between the success rate and battery capacity left. It can be explained that as the battery is running out of power, it can no longer provide enough torque for the motors, and the ultrasonic sensors don't have enough voltage input and therefore provide incorrect feedbacks. These are the reasons that success rate decreases when more and more cycles are run. Two 9V 595 mAh batteries can run 24 times in the sample stair, which means the desired 5-hour working time require a 15000 mAh battery.

Speed test

The speed test was done by the same time of the battery test. The robot was placed on the sample stairs, and the switch was turned on to see how smoothly the robot could go along stairs. On average, the robot moves 3 inch per second when it is moving horizontally on stairs to collect the dirt, and it takes about 30 seconds for the robot to land on the next stairs after cleaning each step. Based on the calculation, it will take 20.5 minutes for the robot to clean one set of stairs in ME building, which include 14 steps with 58 inch in tread. This meets the cleaning speed requirement, which is cleaning 30 steps in one hour.

There are also some problems involved in the robots when it moves on the stairs. First, when the robot is moving laterally and clean each step, there is drifting in the mecanum wheels that may cause the robot to tip over. The drifting is mainly due to the velocity difference in the mecanum wheels. An algorithm to balance the velocity of four DC motors is embedded to solve this problem. Feedbacks on the angular velocity are obtained from the DC motors with encoders, and the speed of each wheel is corrected to the same value. By using this algorithm, the drifting of mecanum wheels is minimized.

Cleanliness Test

In the cleanliness test, 12 gram bread crumbs is spread on a 3 inch by 6 inch area in the sample stairs. The robot sweep this area and collect the dirt from both the vacuum and the brush. Figure 12 shows the difference before and after the cleanliness test. The weight of the bread crumbs is scaled before and after cleaning. From the figure, approximately 80% of large and small particles are collected by the robot after one cleaning cycle for wood floor. For carpet floor, approximately 85% can be collected by the robot after one cleaning cycle.

The robot cannot meet the criteria of removing 99% dirt in one cleaning cycle. This problem can be solved easily in manufacture phase by using a more powerful vacuum and adding additional cleaning cycles. Due to the limitation of time and budget, the vacuum used here is an old vacuum from a 3 years cleaning robot. One good example would be the latest version of the samsung powerbot which has powerful vacuum with high efficiency.

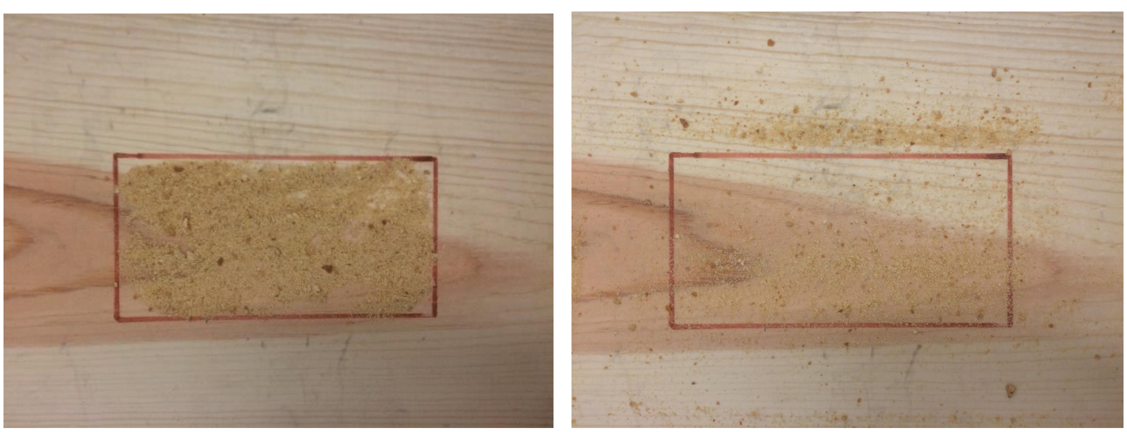

Figure 12: Results of cleanliness test. The left picture is the dirt before cleaning, the right picture is after cleaning.

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Conclusion and Future Improvements

Nimbus 2000 has achieved the basic function of the concept “stair-cleaning robot”: to automatically clean and climb down stairs. Better performances are guaranteed is better and smaller ultrasonic sensors are utilized, or a rechargeable battery with larger capacity is implemented. However, the stair-cleaning robot is incapable of cleaning the edges and this can be solved by adding spiral brushes on the side which will push the dirt to the middle. Another way to relieve the problem is making the robot more compact, because the smaller the robot is, less area of blind spots there will be. A more sophisticated control system can be embedded into the final design and enable the robot to avoid obstacles.

In the final design, as long as customer set the initial position of robot, the system can execute detection, climbing, cleaning in order, which leaves customers completely free to do whatever they like instead of dealing with dirty stairs. Great marketability is predicted for this concept as there is an urgent need asking for an effective tool to automatically work on stairs. However, to make this product available on market, the total cost must be cut down to ensure reasonable retail price, plastic enclosure needs to be added to make the stair-cleaning robot aesthetically acceptable, and it should have reliable and stable performance since “80% cleanliness” is far from enough.

References

[1] Kudzu. (Date of publication not indicated). HOW MUCH COULD I PAY FOR CARPET CLEANING? Retrieved from
http://www.kudzu.com/article/How-much-could-I-pay-for-carpet-cleaning-id9968

[2] Boling Rive LLC. (Debary 17 2015). What Injuries Are Suffered From a Fall Down The Stairs? Retrieved from
http://www.bolingriceatlanta.com/what-injuries-are-suffered-from-a-fall-down-the-stairs/

Nimbus 2000

Appendix I- Previous Reports

Problem Definition Report

Why is it important?

Cleaning dirty stairs can be exhausting and sometimes dangerous. Compared to wooden or carpeted floor, there are much more blind angles and edges, which are perfect shelters for dirt or dust to accumulate. It can be either time-consuming (it usually takes 2-5 minutes per stair to be fully cleaned), if you choose to clean by hand, or expensive ($3 per stair, labor fee not included [1]). In addition, it reduces comfortable sensation and may even cause back injuries or worse in some extreme cases [2].

What do we know?

Benchmarks:

- Vacuum robot (iRobot Roomba 650, $375)

The product is shaped like a disc with a diameter of 13.39 inches and weighs 7.9 lb. The robot applies a spinning side brush to clean along wall edges, a counter-rotating brush to pick up dirt, dust debris and hairs from the floor, and a vacuum to suck the dirt and hair of the brush into the bin. The robot can clean the carpets, tile and hardwood floors, but not for stairs.

- Mopping robot (iRobot Braava 380t, $255)

The product is mainly for mopping hard-surface floors, featuring a pro-clean system, and cube-to-cube navigation system. The product is rectangular shaped with a dimension of 3 x 8.5 inches and weighs 4 lb. Similar to Roomba 650, this mopping robot cannot be applied to stairs.

- Handhold cleaning equipment

Besom, electric vacuum cleaner, and duster cloth, those methods can only assist instead of undertaking the cleaning process automatically, the efficiency is dependent on human labor.

Mechanism investigation:

The mechanism or physics behind this project topic can be mainly divided into two categories: stair-climbing part and cleaning part. Research has been done on some of the stair-climbing robots developed by many research teams to fully understand their mechanisms.

Table 1. Research on climbing methods

Method	Pros	Cons
Track	easy to control; work for flat floor	unstable climbing process; inefficiency
Vertical lifting	efficient; less blind angle	hard to design; control difficulty
Tri-lobe wheel	easy to build; easy to control	tipping risk; harmful for wooden stairs
Wheel with high friction	easy to build; easy to control	tipping risk; total weight is critical constraint
Legs	smooth and accurate control of mass center; extensive application	hard to accomplish; costly

From the benchmark research as described before, there are five main mechanisms on the cleaning method. Most of the sweeping robots on current market utilize either moisten mopping or vacuum, brushing combined with rotating. Advantages as well as disadvantages are listed in the table below.

Table 2. Research on cleaning methods

Method	Pros	Cons
Vacuum	efficient; compatibility for dirty	noisy; contact required
Steaming	disinfection; carpet friendly	heavy; large energy consumption;
Mopping	wooden surfaces friendly,	replacement; low tolerance for hard mutter
Brushing	compatibility for dirty	have hair curling problem
Rotating	solve hair curling problem	disability for collecting
UV-Sanitizi ng	Efficient sanitizing	Only for sanitizing

What is the gap?

There are urgent needs asking for an automatic machine to free people, especially housewives, from the tiredness of cleaning dirty stairs. Based on benchmark research, current products can either clean the flat floor automatically, or provide with supplemental tools in the cleaning process. However, none of them has fully solved the problem, and that motivated

Nimbus 2000 to work on this project and come up with a design that can provide a fast, safe, automatic and reliable cleaning system for dirty stairs.

The challenges of the problem include the complicated three-dimensional geometry of stairs compare to flat ground, combination of cleaning and climbing mechanism, insensitivity and tolerance for small geometry uncertainties.

What will we do?

Nimbus 2000 will combine two to three cleaning methods with one climbing mechanism, therefore extending the application scope of automatic cleaning robots available on current market. Based on previous research, brushing, rotating and vacuum are the most efficient and convenient cleaning methods that may be applied into this stair cleaning robot concept. As for the climbing part, using belt and self-lifting are the best two solutions to accomplish the function. Several possible solutions have been proposed as preliminary designs, among which the best two ideas are described below:

- Since that the sweeping robot on current market is capable of moving, rotating and cleaning, the problem can be fully addressed by inserting four extractable beams into the machine. After the robot finishes cleaning the upper stair, it will extend part of its body in the air and let down two of these extractable beams. It will extend further more until the other two beams are able to come down and support itself, and then it will stand on the lower stair with its main body supported. After lowering itself on the ground, it can continue cleaning on the next step of stair.
- The other design is to utilize a “tank-like” machine to climb up and down stairs with belts. An extractable beam will reach in or out according to the distance between the machine and the ground, to let the cleaning equipment (possibly brush and vacuum) firmly touch the ground. Going up and down would be one working cycle, and the whole cleaning process will be accomplished by changing to different parallel climbing routes.

Possible safety problem and tasks list

The robot may flip backwards or fell from stairs while cleaning, which poses a hazard to surrounding people. In order to avoid this, Nimbus 2000 plan to design a tail for the robot to prevent turning over and also maintain its balance. Also, a dangerous sign will be posted near the stairs before and throughout the whole testing. Sensors, as well as a light & alert system will be integrated into the stair cleaning robot to ensure a safe cleaning process. In order to limit the tipping hazard, a sample stair with fewer steps will be made and used before it is confirmed that testing can be done on real stairs safely.

This project will be divided into several major parts: design, manufacturing, data acquisition, processing and control.

Nimbus 2000

Table 3. Gantt chart

	Wee k 1-4	wee k 5	wee k 6-7	wee k 8	wee k 9	wee k 10-1 1	wee k 12	wee k 13	Major responsibilitie s
Preliminary motion design									Yucheng
Preliminary cleaning design									
Preliminary motion test									
Secondary motion design									Yiming
Secondary motion test									
Secondary cleaning design									
Secondary cleaning test									
Tipping test									Jiayun
cleaning test									
battery life test									
warning system test									
Final design									Liu
Final test									

There are 4 main tests should be done before the final presentation.

1. The tipping test.
   This test will be done in the sample stair we made in order to limit the tipping hazard. Let the robot goes up and down 50 times and record at what kind of condition it will tip. Extreme situations will also be tested, like moving at the edge of the stair.

2. The cleaning test:
   The score of the cleanliness test is out of a total of 100 points. Certain amount of sand and talc is used to test how well the system can clean the floor.

3. The battery life test
   Fully charge the robot and let it work unit it run out of battery. Calculate the average working time.

4. The Warning system test

20 people will be required to test if the light & alert system works for them. Also, tennis balls will be put on stairs to see if the robot can detect them and avoid that area.

CDR Report

Executive Summary

The objective of this project is to design an automatic cleaning robot that clean the standard stairs covered with carpet, hardwood or tiles in house and buildings. Cleaning stairs can be exhausting and likely to cause back injuries in some extreme cases. Based on the benchmark research, none of current products can be used to clean stairs automatically and there is great market potential for the stairs cleaning robot. Several engineering criteria are established to evaluate the project. The product is expected to clean 99% of dirt and its total cost should be within 500$. The robot will only go down stairs, cleaning both top and front sides of each step. In concept generation, the project is separated into two parts based on its function: the climbing part and the cleaning part. The combination of brushing, rotating and vacuum methods will be chosen as the final cleaning concept. The vertical lifting method is chosen as the final climbing concept. The concept is then detailed into a cleaning robot featured by two gear-rack system to lift and lower the wheels, four mecanum wheels powered by DC motors on the two sides of the robot and a free turning wheel in the middle. There is a warning system that detects the tipping and informs the users. The robot will stop its motors whenever the tipping hazard is detected.

Problem Definition

The project aims to design an automatic cleaning robot that can clean the standard stairs in house and buildings. The robot will sweep each steps and clean both top and front surfaces of the stairs. The robot may only go down the stairs, since it requires lower power for the moving system of the robot and there may be more tipping hazard in climbing stairs.

The size of the standard stairs is defined by three dimensions: rise, run and tread (Shown in Figure 1). According to Council of American Building Officials (CABO), unit run should be at least 10 inch and unit rise should not exceed 7¾ inch. The average tread is from 2 feet and 8 inch to 3 feet and 6 inch.[1] The Nimbus 2000 is mainly work for stairs which has unit run from 12 inch to 18 inch, unit rise up to 7¾ inch and unit tread from 2 feet and 8 inch to 3 feet and 6 inch.

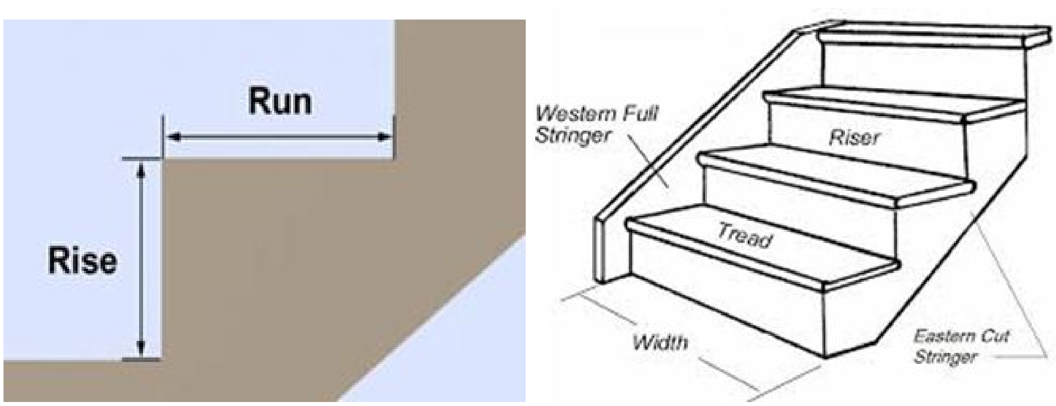

Figure 1. Diagram of standard stairs

The physics of the problem is to move the product onto next step without tipping hazard. The project also need to consider the best way of cleaning different kinds of dirt from different kinds of surfaces such as carpet, hardwood and tile.

The target customers for Nimbus 2000 are people who have to clean stairs frequently, like housewives and cleaners of a building. Usually they spend a lot of time to clean the stairs because there is no automatic machine which can help them. The stairs have many blind angles and edges, meaning that it would require more time than cleaning the same area of the flat floor. It usually takes 2-5 minutes per stair to be fully cleaned. If you don't want to waste your time, hiring someone is a good option. However, it could be super expensive. Usually, it is $3 per stair plus the labor fee. Also, as we all know, cleaning stairs can be painful because it may cause back injuries in some extreme cases.

There are several cleaning products in the current market that can help users to clean the flat floor or stairs:

- Vacuum robot (iRobot Roomba 650, $375)

The product is shaped like a disc with a diameter of 13.39 inches and weighs 7.9 lb. The robot applies a spinning side brush to clean along wall edges, a counter-rotating brush to pick up dirt, dust debris and hairs from the floor, and a vacuum to suck the dirt and hair of the brush into the bin. The robot can clean the carpets, tile and hardwood floors, but not for stairs.

- Mopping robot (iRobot Braava 380t, $255)

The product is mainly for mopping hard-surface floors, featuring a pro-clean system, and cube-to-cube navigation system. The product is rectangular shaped with a dimension of 3 x 8.5 inches and weighs 4 lb. Similar to Roomba 650, this mopping robot cannot be applied to stairs.

- Handhold cleaning equipment

Besom, electric vacuum cleaner, and duster cloth, those methods can only assist instead of undertaking the cleaning process automatically, the efficiency is dependent on human labor.

From the research results above, the vacuum robot and the mopping robot are good solution for flat floor cleaning, but they cannot be applied on stairs. The Handhold cleaning equipment can be applied on stairs cleaning. Unfortunately, it still requires human labor. Therefore, none of existing products are perfect for stairs cleaning. There is great potential for the stairs cleaning robot to prevail in the current market.

The engineering criteria for evaluating the success of the project are defined as follows:

- **cleanliness**

The most important requirement for a cleaning robot is cleanliness. Nimbus 2000 should able to clean more than 99% of dirt including hair, small particles and other dirt. Also, the robot should be able to clean blind angle and edges.

- **(Efficient) Cleaning speed**

Typically, the tread of the stair is around 3 feet and 6 inch. The robot should be able to clean more than 30 steps per hour.

- **Lifetime**

This robot should be able to work more than 3 years.

- **Energy saving**

It should be able to work for 5 hour per charge. If there is problem to find the suitable battery, power cord can be used instead.

- **Reliability and Stable**

Safety is the most important part Nimbus 2000 focus on. This robot should not cause tipping hazard. Warning system will be added in order to warn people around.

- **Work for multi-surface**
  The robot should be able to clean wooden, carpeted and tile.
- **Applicable for stairs with different rise**
  The rise is different from stairs to stairs. Based on the council of American Building officials, the unit rises should be less than 7and3/4 inches. Therefore, the robot should be able to be applied to different rise.
- **Costless**
  The robot should be around $500.
- **Easy to clean itself**
  The way to clean the robot itself should be easy. All dirt will be collect to a box and users only need to open that box and clean the dirt inside.

Design Solution

The current design is featured by two gear-rack system to lift the wheels, four mecanum wheels powered by DC motors to move the robot perpendicularly and parallel to the step and a free turning wheel in the middle to support the main body. Cleaning components are located under the main board of the robot. There are brush and rotator on the left side and vacuum on the right side. When the robot move to the left, the large particles will be collected by the brush and rotator first and the small particles will be collected by the vacuum. The complete drawings of the design is shown in Appendix: A.

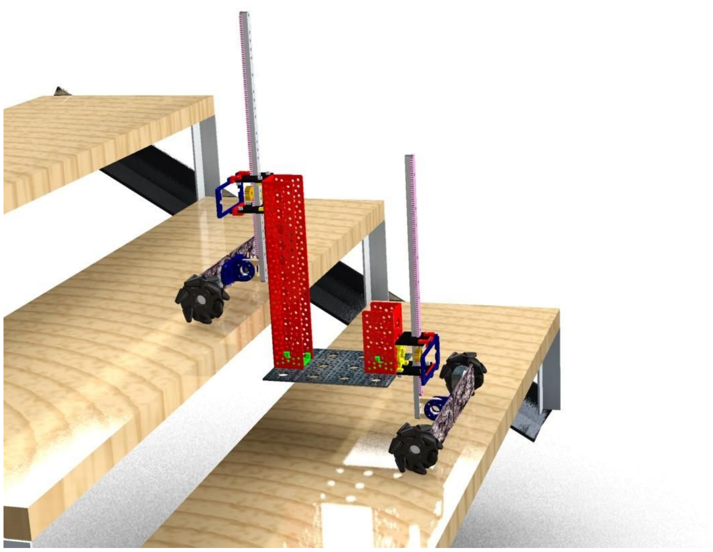

Figure 2. The robot working with the stairs (There is also a free turning wheel at the middle)

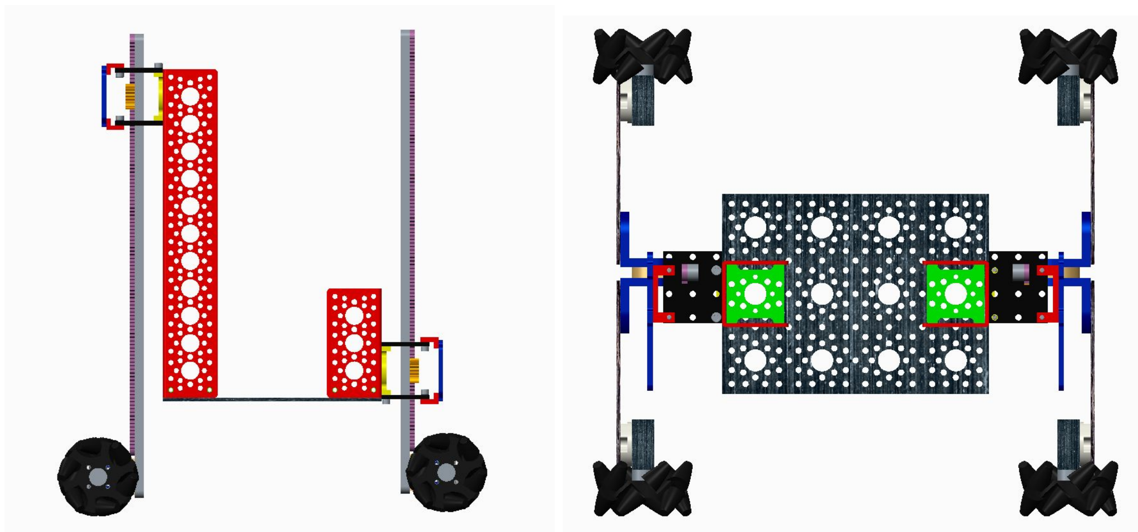

Figure 3. The side view (left) and top view (right) of the robot

Arduino Mega board with a motor shield will be used to control the whole robot. The control system has a capacity to control 2 servos and 4 DC motors with additional 54 digital I/O channels to control the cleaning components. Ultrasonic sensors will be installed under the rack so that the robot can detect the edge of the steps and lower the wheels to desired depth. A 6V battery may be used for the power supply of the whole system, if not enough the robot can be connect to the power line by cables.

The Warning system is an important system for safety consider. The warning system should be able to detect the tipping hazard by the ultrasonic sensor which is located at the front bottom of the robot. The distance detected by the ultrasonic sensor should range from zero to the rise of the stairs, and change smoothly along with angular control of the servomotor. When rapid change in the distance detection is observed, the system will know that the robot is tipping and cut out power immediately, which will limit the possible damage to the minimum.

Also, lights warning will be turned on when the robot is running. Therefore, people will know there is a robot in operation.

How to stop and where to stop the robot is another important topic for Nimbus 2000. The distance sensor at front surface of the robot should be able to detect the change of the unit run. If it can’t find the front surface in a regular unit run range (The robot will measure the unit run of the stairs before turn on the cleaning model.), it will know it reach the top. The robot should not stop right at the edge of the stair nor in front of any door. It may require used to set a stop position for the robot. For example, put an emitter at the desired stop position. The robot can find that place and stop right there.

Most of our time will be spent on programming the control section. Most of parts can be purchased online.

Concept Generation

In order to better address the main function of the project, the concept generation is divided into two parts: the climbing methods and cleaning methods.

Figure 3 shows the cleaning methods that are prevailing in cleaning robots or accessible for housekeeping uses. The cleaning robots in current market generally applied brushing method to cleaning large particles, rotating method to clean corners and the sides of the robot and vacuum to clean small particles. Brushing method is to collect the large particles by rotating different kinds of brushes. Rotating method is to gather the dirt that are beyond the range of brush. Mopping method can moisten the surface and remove sticky dirt from the surface, but it is mainly for hardwood and tile surface. Steaming method can kill bacterial and fungus and work well on carpet. Vacuum is to suck the small particles from the surface. UV-sanitizing is to kill the bacterial and fungus by emitting ultraviolet light.

Figure 4 shows different kinds of climbing methods that are generated during the concept generation process. In the first design in figure 4, the robot uses track to move up and down the stairs. The track should have high friction to avoid the slipping during the climbing process. A tail may be added to the back to support and balance the robot when the two ends of the robot are suspended in the air. In the second design in figure 4, the robot will have multiple set of wheels that can move vertically. When the robot is moving down to the next stairs, it lowers its front wheels first and go forward. When the main body of the robot moves to the next step, it withdraw its wheels and lower the main body to the ground. The third design in figure 4 shows that the robot is equipped with high-friction wheels so that it can climb the stairs by simply rotating its wheels. The rear wheels can support the robot and prevent it from tipping. In the fourth design, the wheels of the robot are designed as tri-lobe wheel, which are shaped like a three-blade fan. The tri-lobe wheel is large enough so that the robot can climb the stairs by rotating its wheels. In the fifth design, the robot may have multiple legs that can climb the stairs like spider or dogs.

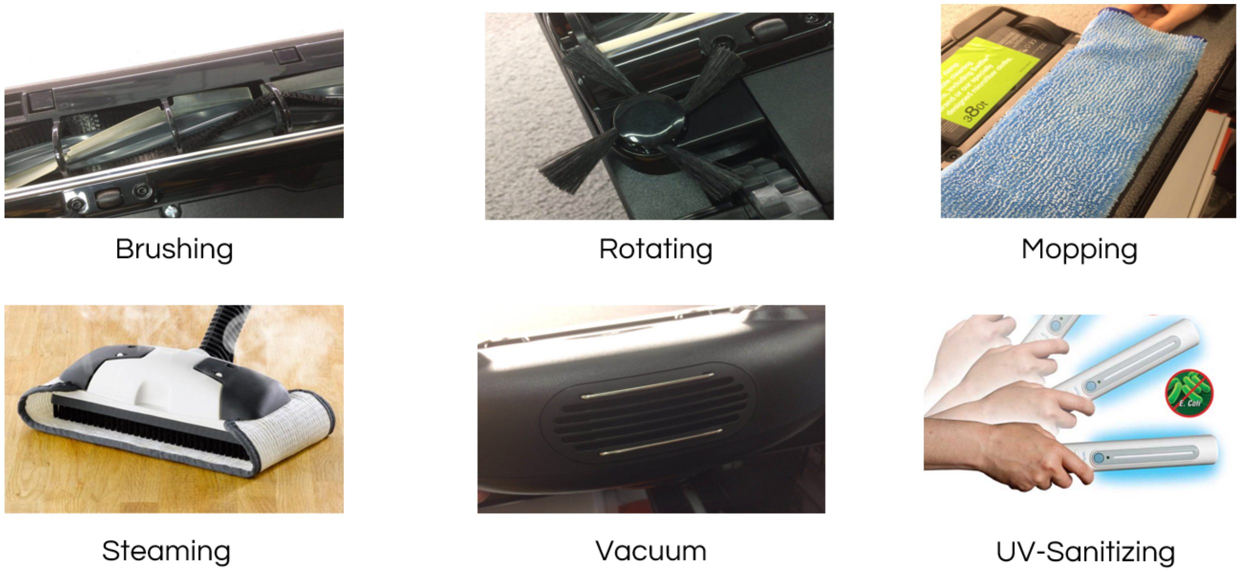

Figure 4. The pictures of design concepts for cleaning

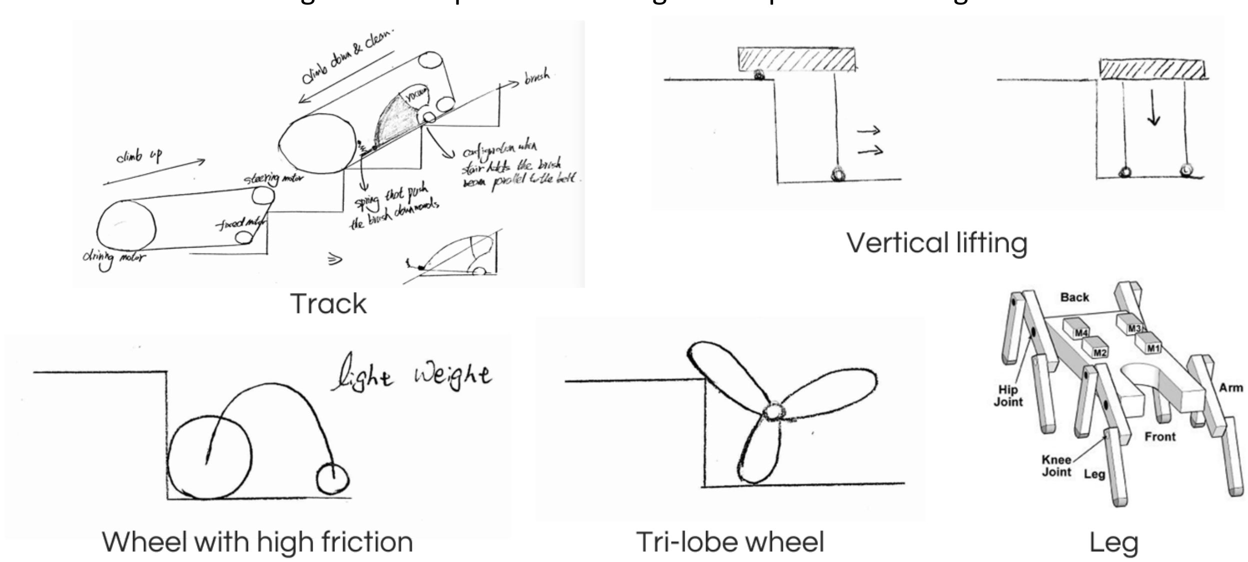

Figure 5. The sketch of design concepts for climbing

The detailed pros and cons comparison for cleaning and climbing concepts are shown in Table 1 and Table 2. The decision matrix of cleaning concepts and climbing concepts are shown in Table 3 and Table 4. From table 3, Vacuum, brushing and rotating methods scores highest among all of the cleaning concepts. UV-light sanitizing also got high scores. The UV-sanitizing is a cool idea and none of current products are using this idea. However, more research should be done to prove that it can be safely used on carpet. In table 4, track and vertical lifting concepts got highest scores.

Based on the results from decision matrix and comparison of pros and cons, we decided to choose the combination of brushing, rotating and vacuum methods as the cleaning concept. The three cleaning methods are combined together because the three cleaning method deals with different kinds of dirt. For the climbing concept, a further consideration between track and vertical lifting design is required.

Table 1. Pros and Cons for cleaning concepts

Method	Pros	Cons
Vacuum	Great cleaning speed; Work well for both small and big particles	Produce noise; Sucking effect highly depends on the distance to surface
Steaming	Can kill bacterials and fungus; Work best on carpets	Add much weight on the machine; Require high input power; May harm wooden stairs
Mopping	Not using electricity; Gentle on sensitive surfaces; Work best on wooden surface	Need to replace parts frequently; Hard particles attached may harm the wooden stairs
Brushing	Work well for all dirt, small and big particles	Hair curling problem
Rotating	Clean large particles; A good solution to hair curling problem	Cannot collect dirt or small particles
UV-Sanitizing	Can kill bacterials and fungus; Fast	Cannot deal with visible dirt or particles; May result into fading of carpets

Table 2. Pros and Cons for climbing concepts

Method	Pros	Cons
Track	Easy to build; Easy to control; Can also work for flat floor	Balancing problem when climbing; May flip backward
Vertical lifting	Efficient; Can cover most of the area when climbing	Hard to design; Control difficulty
Tri-lobe wheel	Easy to build; Easy to control	Complicated movement of mass center; Hard to combine with cleaning mechanism; May harm wooden stairs

Wheel with high friction	Easy to build; Easy to control	Complicated movement of mass center; Hard to combine with cleaning mechanism; Weight is critical constraint
Legs	Solve balance problem; Work for any kinds of configurations	Hard to accomplish; Moving parts can be costly

The preliminary design was using the track as the climbing method. As mentioned before, the track require high friction and a supporting tail at back. They all made this system super complex and hard to achieve. More than that, it is difficult for this design to have vacuum and brushes that can always follow the ground. Also, the track can't move horizontally along the step. Therefore, it require the robot to move up and down stairs several times to clean all area which may cause more tipping hazard and require more time to clean. Because the track is placed at two sides of the robot, the rotating machine can't go over the track. Therefore, it always has blind area at two sides of stairs.

According to all reasons mentioned above, the track method was changed to the vertical lifting method which is our current design.

Table 3. Decision matrix of cleaning concepts

	Weight	Vacuum	Steaming	Mopping	Brushing	Rotating	UV-Sanitizing
Cleanliness	10	10	7	5	8	8	5
Cleaning speed	10	10	6	8	8	8	6
Clean blind angles and edges	10	7	5	5	9	6	6
Gentle on sensitive surfaces	8	8	8	7	8	8	8
Work for both dirt, small and big particles	7	7	4	4	6	7	2
Costless	5	3	1	5	4	3	2
Wood stairs Friendly	5	5	3	5	4	4	5
Carpet stairs Fridently	5	5	1	2	4	4	5
Easy to clean itself	5	4	4	5	3	2	5
Other benefit	5	3	5	1	1	1	5
Sum	70	62	44	47	55	51	49

Table 4. Decision matrix of climbing concepts

	Weight	Track	Vertical lifting	Tri-lobe wheel	Wheel with high friction	Legs
Stable (No tipping nor slipping)	10	5	8	4	3	5
Applicable for stairs with different rises	10	7	10	6	5	5
Efficient (Time to clean each floor)	9	6	8	5	5	5
Applicable for flat floor (Can move in all directions)	8	6	7	5	6	5
Easy to control	7	5	6	5	5	2
Easy to build	6	6	5	4	4	1
Costless	5	3	2	3	3	1
Compact & Portable	5	3	2	3	3	3
Sum	60	41	48	35	34	27

The backup design is a modified version of vertical lifting concept, which is shown in Figure 5. There are two pair of wheels at the left side and right side of the robot that can be lifted and lowered. The robot turns around a small angle before it goes down stairs and then move forward. The robot lowers its left wheels whenever they are in the air. After the left wheels land on the next step, the robot will continue to go forward and then lower its main body. This design concept may have more tipping problem, and the programming task accompanied with this design may be more complicated.

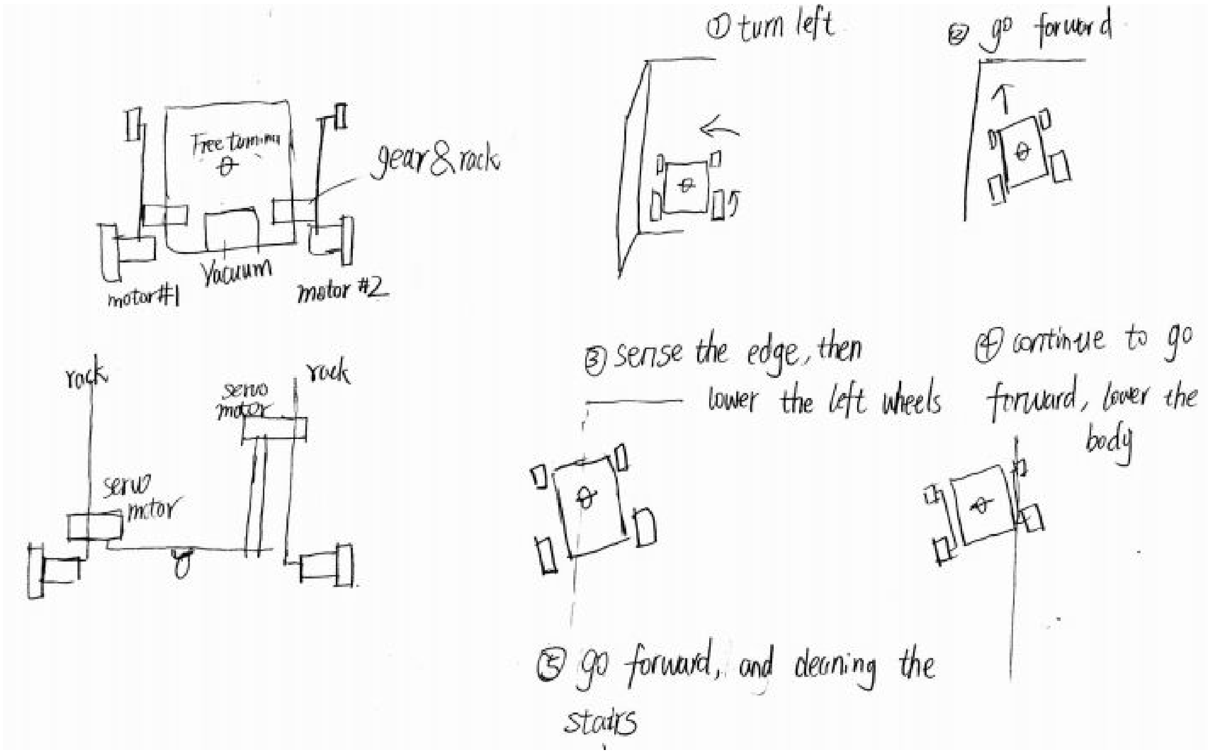

Figure 6. Diagram of the backup design concept

Engineering Justification

The torque of lifting process is 1.228kg*cm according to the assumption of that robot mass is 3.87kg. The torque of servo motor is 13.2kg*cm which is much larger than the required torque.

The size of the robot is also restricted so that the robot can work well on the standard stairs. First of all, the robot should be able to lie on one step. The length of the robot cannot exceed unit run of the step. Then, the motion range of the gear rack system should be larger than the height of one step so that the robot can land on the next step. What’s more, the mass center of the robot should be as low as possible, so as to avoid tipping hazard. The power required to run this system will be calculated after control part is mainly settle down.

Design Details

To fully address the automatic control problem, an Arduino Mega 2560 R3 board will be used as the microcontroller in the stair-cleaning robot. Arduino Mega will be twice expensive as Arduino Uno, but it have a total of 54 digital I/O channels (Uno only has 14). Due to the fact that there are many electrical components (2 Servos, 7 DC motors, 3 sensors) in this project, 14 digital channels is not enough while Arduino Mega is fully capable of the control job.

One obvious drawback of controlling motors directly with Arduino Mega is that the DC current available per digital channel is limited to 40 mA, and even the VCC and GND pins can only stand a DC current of 200 mA. Therefore, an Adafruit motor shield v2.3 will be stacked onto the Arduino Mega board to function as a separate driver for motors. This motor shield will use 14 digital channels from the Arduino Mega and be able to provide power as well as signal input for up to 2 Servos and 4 DC motors. Nimbus 2000 will utilize this motor shield to power the two servo motors in the gear/rack systems, as well as the four micro gearmotors that are connected to the four mecanum wheels. Given a 6V DC power supply, Adafruit motor shield can provide with more stable voltage supply to the drivers and the DC current capability is raised to 1.2A per channel, which will allow motors to draw more torque from the power source.

As for the ultrasonic (distance) sensor, Nimbus 2000 has chosen HC-SR04 as a good candidate for this project. The detection distance of this sensor ranges from 2cm to 5m, and the resolution is 0.3cm, which is good enough for timely position feedback control. Its compatibility with Arduino Mega has been tested.

All motors will be operated at a 6V environment. The servo motor (Hitec, HS-785HB) is characterized by having 3.5 rotations and a very good value of torque (13.2kg.cm). The 90RPM micro gear motors will be purchased from ServoCity. These DC motors have a torque of 1.22 kg.cm, no load current of 40mA and stall current of 360mA, which explains why Adafruit motor shield should be used to prevent from burning out the Arduino board. Angular control will be done on the two servo motors, while the control job on the four gear motors will focus on the direction, rotating speed and delay time. When it comes to the motors for brushing, vacuum and rotating components, however, the control job is simply turning on or off these motors at the right time. But attention must be paid to the current requirements of these motors. Transistor may be used to amplify the current drew from the Arduino channels to prevent overloading. Detailed information about the electrical components can be found in Appendix.

Before operating the stair-cleaning robot, there are a few prerequisites for the users: the user should be aware of the exact values of the rise, run, tread and number of their stairs and type them in the User Interface (which is the Arduino IDE program during preliminary development) as user inputs; the user will have to remove all large particles, such as stones or baby toys, from the stairs; for best cleaning performance, the user needs to place the robot at the left bottom corner on the first stage, facing towards the down side of the stairs, as is shown in the following figure.

Figure 7. Robot placement configuration

After the robot is powered on, the robot will ask for the user inputs about the stairs and wait until the user finishes all the prerequisites. It will change into the cleaning state after the user pushes the "Start Cleaning" button, as is shown in the flowchart below.

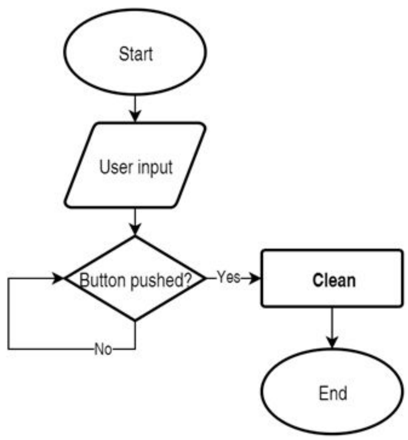

Figure 8. Flow chart in the preparation state

In the cleaning state, the robot will first do a position calibration with the ultrasonic sensor on the front wheels, facing downwards. The robot will move forwards until a distance change is detected by the ultrasonic sensor (ideally increased by the rise of the stairs), and the location of the front edge is determined. Then it will move backwards to the back edge of the stairs, and do one sweeping cycle by moving from the left end to the right end, during which the cleaning components attached to the bottom of the robot will be turned on, and do the cleaning job. After the robot has moved back to the original position (left end), two conditions will be checked by the control system in sequence. First, the control system will check whether if the whole area on the current stage is cleaned, in other words, the robot has gone through all area of the stage. If not, the robot will move forwards some distance, which is determined by the embedded algorithm, and do another sweeping cycle. If yes, the control system will check whether if the robot has cleaning all the stairs, in other words, is the number of stairs equal to the times it has climbed down. If yes, the robot will stop working, and wait for the user to pick it up. If not, it will change into the climbing state.

It should be noted that, the three ultrasonic sensors will be placed at different places on the robot. One will be installed on the front wheels of the robot, as discussed before, to help with the location calibration process as well as prevent tipping hazard (when the distance detected changes rapidly, the control system will shut down all electrical components to minimize the damage). One will be on the right side of the robot against the wall, and the feedback from it combined with the tread from the user inputs will determine how far the robot should move sideways. One will be embedded near the back bottom of the robot's main body, to provide feedback for the control of the two servo motors when lowering the main body in the climbing state, which will be discussed in the next paragraph.

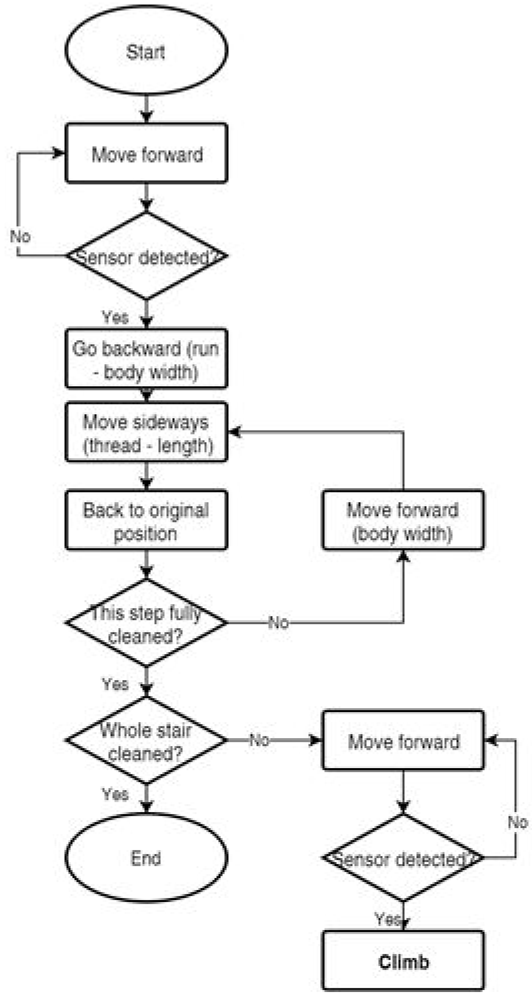

Figure 9. Flow chart in the cleaning state

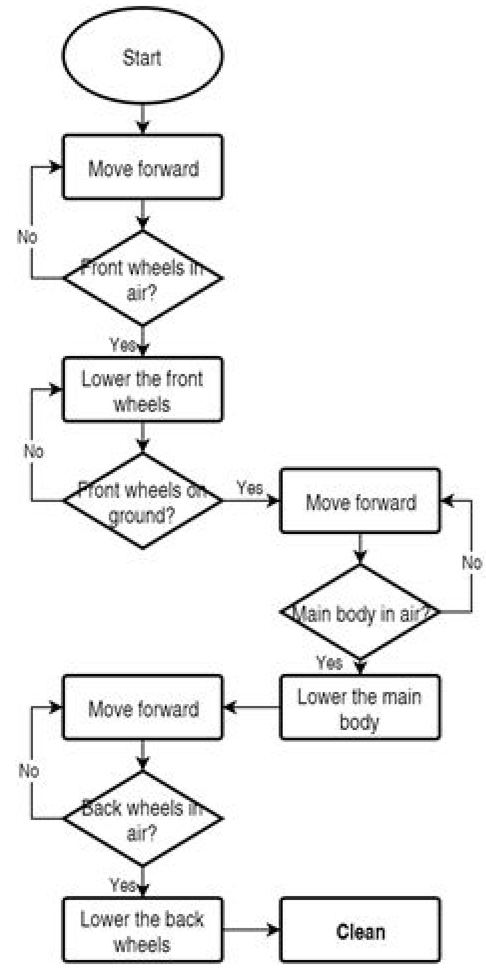

Figure 10. Flow chart in the climbing state

During the climbing state, the robot will climb down to the next stage via lowering different parts of itself in sequence. It will first move forward until it is able to lower its front wheels to the next stage via angular control on the front servo motor. Then, with four wheels supporting the robot, two on the next stage and two on the current stage, it will move forward until its whole main body is on the air. By controlling both servo motors, the main body of the robot will be lowered onto the next stage, and thus the robot will be able to stand with the front wheels as well as the free-turning wheels at the bottom. Similarly, it will move forward and lower its back wheels, and the whole ”Climbing Down” process is finished, after which the robot will change back to the cleaning state. The two ultrasonic sensors facing downwards will provide with distance feedback for the angular control on the servo motors during the whole process

By iterating the “Cleaning - Climbing” process, the stair-cleaning robot is capable of integrating the climbing and cleaning mechanism and thus achieving the primary goal of automatic stairs cleaning for standard stairs.

Team Organization

- Jiayun and Yuchen

Research on benchmarks, cleaning section design, battery life check

- Yiming

Control and programming, tipping test

- Liu

CAD and warning system design and test

Table 3. Updated Gantt chart

	Week 1-4	week 5	week 6-7	week 8	week 9	week 10-11	week 12	week 13	Major responsibilities
Preliminary motion design									Yuchen
Preliminary cleaning design									Liu
Preliminary motion test									Yiming
Secondary motion design									Yuchen
Secondary cleaning design									Jiayun
Control design									Yiming
Cleaning test									Yiming
Tipping test									Liu
Warning system design									Yiming
battery life test									Jiayun
warning system test									Yuchen
Final design									Liu
Final test									Together

There are 5 main tests should be done before the final presentation.

1. The tipping test.

This test will be done in the sample stair we made in order to limit the tipping hazard. Let the robot goes down 50 times and record at what kind of condition it will tip. Extreme situations will also be tested, like moving at the edge of the stair.

2. The cleaning test:
   The score of the cleanliness test is out of a total of 100 points. Certain amount of sand and talc is used to test how well the system can clean the floor.

3. The battery life test
   Fully charge the robot and let it work unit it run out of battery. Calculate the average working time.

4. The Warning system test
   20 people will be required to test if the light & alert system works for them. Also, tennis balls will be put on stairs to see if the robot can detect them and avoid that area.

5. Mecanum wheel test
   The mecanum wheel would have slip and drift problems in some cases. Before we program the control system, mecanum wheels will be tested and the motion trail of the wheels will be recorded. The errors will be fixed in programming section.

Appendix II - CAD Drawings

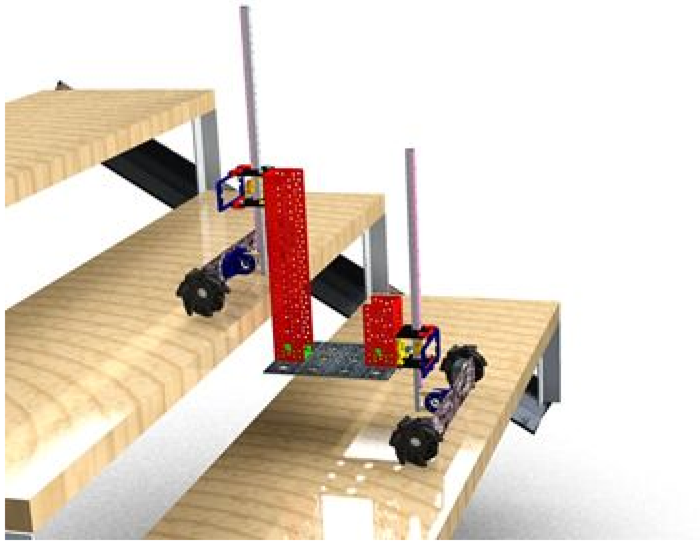

Figure 12. The robot placed on the stairs (Vacuum, brushes and two free turning wheels are located underneath main platform)

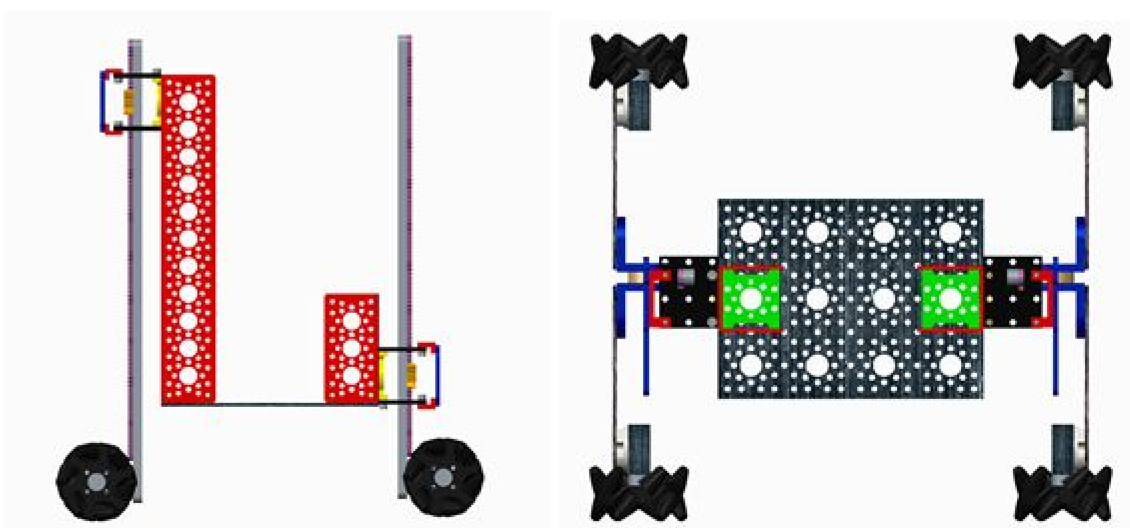

Figure 13. The side view (left) and top view (right) of the robot

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Appendix III - Bills of Materials

Table 2. Bill of materials

Part Number	Description	Quantity	Unit cost	Total	Status
545440	.770 x .770 Hub Adaptor	4	2.99	11.96	Waiting
575116	Quarter Scale Servo Plate A	2	5.99	11.98	Waiting
615278	16T 32P Hitec Metal Gear	2	14.99	29.98	Waiting
615410	Beam Gear Racks	3	5.99	17.97	Waiting
585423	12.32" Aluminum Beams	2	7.99	15.98	Waiting
632144	#6 Standard Washers Pack	1	0.89	0.89	Waiting
585658	Beam Bracket U	4	1.79	7.16	Waiting
585508	90 Dual Side Mount B	2	5.99	11.98	Waiting
545424	90 Quad Hub Mount B	2	4.99	9.98	Waiting
632106	1/4" Socket Head Machine Screw	2	1.69	3.38	Waiting
632108	5/16" Socket Head Machine Screw	3	1.79	5.37	Waiting
632118	5/8"" Socket Head Machine Screw	3	2.59	7.77	Waiting
632142	6-32 Nylock Nuts Pack	6	1.59	9.54	Waiting
585442	3" Aluminum Channel	1	3.99	3.99	Waiting
585450	9" Aluminum Channel	1	7.99	7.99	Waiting
545360	90 Quad Hub Mount C	2	5.99	11.98	Waiting
585004	4.5" * 12" Flat Aluminum Panel	1	13.99	13.99	Waiting
545412	90 Hub Mount A	2	4.49	8.98	Waiting
545400	90 Hub to Hub Mount	6	4.99	29.94	Waiting
585580	Flat Triple Channel Bracket	8	2.49	19.92	Waiting
632128	1-1/4" Socket Head Machine Screw	1	3.59	3.59	Waiting
555120	Micro Gearmotor Enclosure	4	0.99	3.96	Waiting
585424	90 Single Angle Channel Bracket	4	1.59	6.36	Waiting
	Hitec HS-785HB Winch Servo, Rotation: 2700 degree	2	57.75	115.5	Waiting
	Pawhut Portable Pet Stairs for Cats and Dogs	1	59.95	59.95	Delivered
	Mecanum Wheels 4 pk	1	69.95	69.95	Delivered
		Sum		500.04	

Appendix IV - Torque Calculation for Servo motor on gear/rack system

Torque calculation

Predicted robot mass M=3.87Kg, gear pitch diameter=0.5 inch

F= M/2 = 1.935kg

T = F * D/2

= 1.935KG * 1.27cm/2

= 1.228 kg*cm

Torque of servo: 13.2 kg*cm > 1.228 kg*cm

Appendix V - Arduino Code

```
//ME463, Spring semester 2016, Purdue University
//Nimbus 2000, adviser Eric Nauman
//Coded by Yiming Ding, Jiayun Shao
//Other team mebers: Liu Hong. Yuchen Zhang
//Last updated: April 4 2016


//Library
#include <Wire.h>
#include <Servo.h>
#include <Adafruit_MotorShield.h>
#include "utility/Adafruit_MS_PWMServoDriver.h"
Adafruit_MotorShield AFMS = Adafruit_MotorShield();


//Switch settings
#define SwitchPin 30
int SwitchState = HIGH;
int SwitchReading;
int SwitchPrevious = LOW;
long time = 0;
long debounce = 50;


//Ultrasonic sensor1, attached on the right side
#define Sensor1TrigPin 30
#define Sensor1EchoPin 31
long Sensor1Duration;
float Sensor1Distance;


//Ultrasonic sensor2, attached on the front
#define Sensor2TrigPin 32
#define Sensor2EchoPin 33
long Sensor2Duration;
float Sensor2Distance;


//DC motor settings
Adafruit_DCMotor *myMotorLB = AFMS.getMotor(4);
Adafruit_DCMotor *myMotorLA = AFMS.getMotor(1);
Adafruit_DCMotor *myMotorRA = AFMS.getMotor(3);
```

```
Adafruit_DCMotor *myMotorRB = AFMS.getMotor(2);
int LBSpeed = 255;
int LASpeed = 255;
int RASpeed = 255;
int RBSpeed = 255;
int CleaningState = 2;

//Servo settings
Servo FrontServo;
Servo BackServo;

void setup() {
 Serial.begin (9600);
 //Switch settings
 pinMode(SwitchPin, INPUT);

 //Ultrasonic sensor1
 pinMode(Sensor1TrigPin, OUTPUT);
 pinMode(Sensor1EchoPin, INPUT);
 //Ultrasonic sensor2
 pinMode(Sensor2TrigPin, OUTPUT);
 pinMode(Sensor2EchoPin, INPUT);

 //DC motor settings
 AFMS.begin();

 //Servo settings
 FrontServo.attach(9);
 FrontServo.writeMicroseconds(1670);
 BackServo.attach(10);
 BackServo.writeMicroseconds(1750);
}

void loop() {
 //Switch settings
 SwitchReading = digitalRead(SwitchPin);
 if (SwitchReading == HIGH && SwitchPrevious == LOW && millis() - time > debounce) {
  SwitchState = HIGH;
 }
 time = millis();
```

```
 //MoveOnStatge
 if (SwitchState == HIGH) {


   if (CleaningState == 0) {
     Sensor1();
     MoveToRight();
   }
   else if (CleaningState == 1) {
     Sensor1();
     MoveToLeft();
   }
   else if (CleaningState == 2) {
     Sensor2();
     MoveToFront();
   }
   else if (CleaningState ==3) {
     FrontServo.writeMicroseconds(700);
   }
   else if (CleaningState ==3) {
     FrontServo.writeMicroseconds(700);
   }
 }
 delay(100);
}


void Sensor1() {
 digitalWrite(Sensor1TrigPin, HIGH);
 delayMicroseconds(2);
 digitalWrite(Sensor1TrigPin, LOW);
 Sensor1Duration = pulseIn(Sensor1EchoPin, HIGH);
 Sensor1Distance = (Sensor1Duration / 2) / 29.1;
}


void Sensor2() {
 digitalWrite(Sensor2TrigPin, HIGH);
 delayMicroseconds(2);
 digitalWrite(Sensor2TrigPin, LOW);
 Sensor2Duration = pulseIn(Sensor2EchoPin, HIGH);
 Sensor2Distance = (Sensor2Duration / 2) / 29.1;
}
```

```
void MoveToRight() {
 if (Sensor1Distance > 8.5) {
     Serial.println(Sensor1Distance);


  myMotorLB->setSpeed(LBSpeed);
  myMotorLB->run(BACKWARD);
  myMotorLA->setSpeed(LASpeed);
  myMotorLA->run(FORWARD);
  myMotorRA->setSpeed(RASpeed);
  myMotorRA->run(BACKWARD);
  myMotorRB->setSpeed(RBSpeed);
  myMotorRB->run(FORWARD);
 }
 else {
  myMotorLB->run(RELEASE);
  myMotorLA->run(RELEASE);
  myMotorRA->run(RELEASE);
  myMotorRB->run(RELEASE);
  CleaningState = 1;
 }
}


void MoveToLeft() {
 if (Sensor1Distance < 30) {
     Serial.println(Sensor1Distance);


  myMotorLB->setSpeed(LBSpeed);
  myMotorLB->run(FORWARD);
  myMotorLA->setSpeed(LASpeed);
  myMotorLA->run(BACKWARD);
  myMotorRA->setSpeed(RASpeed);
  myMotorRA->run(FORWARD);
  myMotorRB->setSpeed(RBSpeed);
  myMotorRB->run(BACKWARD);
 }
 else {
  myMotorLB->run(RELEASE);
  myMotorLA->run(RELEASE);
  myMotorRA->run(RELEASE);
  myMotorRB->run(RELEASE);
```

```
    CleaningState = 2;
  }
}


void MoveToFront() {
  if (Sensor2Distance < 10) {
    Serial.println(Sensor2Distance);
    myMotorLB->setSpeed(180);
    myMotorLB->run(BACKWARD);
    myMotorLA->setSpeed(180);
    myMotorLA->run(BACKWARD);
    myMotorRA->setSpeed(180);
    myMotorRA->run(FORWARD);
    myMotorRB->setSpeed(180);
    myMotorRB->run(FORWARD);
    Serial.println("GO forward");
  }
  else {
    myMotorLB->run(RELEASE);
    myMotorLA->run(RELEASE);
    myMotorRA->run(RELEASE);
    myMotorRB->run(RELEASE);
    Serial.println("STOP");
    CleaningState = 3;
  }
}
```

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