CubeScrub

A compact robotic arm designed for efficient, gentle cleaning, housed within a sleek, cube-like base — ideal for the cleaning of fragile, small-scale items.

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INTRODUCTION

Cleaning, while a necessary task, can often be tedious and time-consuming. Although some people find the process relaxing or even therapeutic, many would prefer to delegate this responsibility to machines. Devices like robotic vacuum cleaners and other autonomous cleaning tools have gained popularity for their ability to save time and reduce the physical effort involved in maintaining a clean environment. Inspired by these technological trends, our project aims to develop a robotic arm designed specifically for cleaning tasks. We hope to create an efficient, flexible, and customizable cleaning tool that can adapt to various environments and surfaces.

Initially, we envisioned creating a more complex robotic arm, but after consulting Professor Zhang, we decided to scale down our project. Our final deliverable will consist of a single-segment robotic arm that is attached to the top of a cube-like box. While simplified in form, the arm will still be capable of moving across all three spatial dimensions. Movement along the X and Y axes will be restricted to straight lines (rectilinear motion). For movement across the Z-axis, we have two design prototypes that will be explored below: an extendable robotic arm segment, or rectilinear motion along the Z-axis. Z-axis motion in this instance refers to height adjustment capabilities, which would enable users to clean surfaces of varying elevation. By combining rectilinear movement across X and Y directions with Z-axis height adjustment, the robotic arm can seamlessly maneuver across three-dimensional space, optimizing its cleaning reach.

The versatility of this robotic arm is further enhanced by the attachment of a rotating cleaning disk at its end. Users will be able to attach various types of cleaning cloths, such as microfiber cloths for delicate surfaces. This customizable design ensures that the robotic arm can adapt to different cleaning scenarios, while the disk rotation enables optimal scrubbing. The disk is attached to the arm through a pivot joint that allows a 180 degree movement (either up/down or left/right, depending on how the joint is attached) that will enable smooth gliding across different surfaces. Because the joint is limited to 180 degrees, in order for the cleaning disk to have a 360 rotation reach, the arm will be able to spin on its own axis. This design will enable the disk to clean and reach all surfaces.

The arm will be manually controlled via an attached controller, which will allow users to guide the arm's movements according to their needs. Given that the arm's movement is restricted to the X, Y, and Z axes, users should find the arm straightforward to navigate and control. By limiting motion to rectilinear paths, we eliminate the complexities associated with diagonal or multiaxial movements, which can sometimes make robotic systems difficult to operate.

DESIGN OVERVIEW

From a high-level perspective, the design of our robot centers around a vertical arm that is suspended from the top of a cube-like box structure. The cube serves as the foundation and base for the entire robotic system, housing the essential hardware and mechanical components, such as motors and tracks, which are critical for enabling precise movement.

The vertical arm, extending from the top of the cube, is the central tool designed for performing various cleaning tasks. It is designed to move in three dimensions, ensuring flexibility and versatility in accessing different positions and surfaces of the object being cleaned. The arm's movement is restricted to rectilinear paths, moving in straight lines parallel to the X, Y, and Z axes. This ensures that the arm can cover the full plane of the cube's top surface and provides height flexibility, enabling comprehensive cleaning coverage for different surfaces at different elevations. By limiting the movement to straight lines and avoiding diagonal or complex rotational motions, we achieve a more intuitive and mechanically reliable system. Whether the target surface is above or below the arm's initial position, the vertical extension allows the robot to adapt to the cleaning environment without requiring manual repositioning.

To enable movement along the X and Y axes, the cube is designed with a set of tracks. There are two parallel tracks aligned with the Y direction, and a third set of tracks that spans between them to support movement along the X direction. These tracks form the framework for the arm's movement across the horizontal plane. Movement along the tracks will be powered by stepper motors, with one motor for each axis. Each stepper motor provides precise control over the arm's movement, ensuring that it can position itself accurately along both axes. For the Z-axis, tracks will be placed orthogonal to the X-Y tracks, with another stepper motor responsible for providing the necessary height adjustment. The arm's movement will be controlled by users via our attached controller (see more below).

At the end of the robotic arm, a rotating cleaning disk is attached, which serves as the primary cleaning tool. The disk is designed to accommodate various cleaning materials, such as microfiber cloths, rags, or disinfecting wipes, depending on the specific task at hand. These materials will be easily attached to the disk using a Velcro system, allowing users to quickly switch between different cleaning tools as needed. The rotation of the cleaning disk is powered by a servo motor. In addition to the rotating cleaning disk, the disk is mounted on a pivoting joint that allows for 180-degree rotation. This pivoting mechanism adds another layer of flexibility, enabling the mop head to adjust its angle freely as the arm moves. The arm itself will also have the ability to rotate around its vertical axis, simulating 360-degree motion.

An additional feature we're looking to explore is an automatic water sprinkler. The base will have a container with water attached to it and a tube along the arm of the machine that connects the water container to the disk. We would also need to implement a water pump mechanism that can push water through the tube, which can end in a nozzle position where the disk is. The spraying motion can be activated at intervals based on cleaning requirements and surface types. We are also looking into the possibility of replacing the static base by a platform with wheels that can be remote controlled — this can prove to be difficult since an additional software component would be needed to control the wheels' movement.

FUNCTIONAL UNITS

We segmented our functional components based on a modular approach, where each component has a distinct function. As per the high-level design description above, the current planned units are:

- Cube Structure
- Tracks and mechanisms that enable movement along the X-axis
- Tracks and mechanisms that enable movement along the Y-axis
- Mechanisms that allow movement along the Z-axis
- Robotic arm
- Rotating cleaning disk

EXPECTED COMPONENTS

1. The Cube Structure

For the larger structure that would contain the setup for our robotic arm, we had planned to create a cube (containing either 4 or 5 sides — the top and 4 other sides, or just 3 others) using plastic acrylic, so that it would be see-through.

In our prototype, we created a mockup of this design using cardboard. We went with the 4-side design since our cardboard is opaque and we wanted to be able to demonstrate the functions within our cube.

One of the key takeaways we had from this design was that we definitely needed a sturdy setup. While the 4-side cube can stand on its own, to support the weight of the components inside, the material we use will need to be quite sturdy (especially because we plan to attach the robotic arm and X/Y tracks to the top of said cube). The cardboard we were initially working with was a little flimsy, and it was bending with the weight of our robotic arm inside, so we had to add additional support to it. Then we had no trouble with our design.

2. X-Axis Tracks (Left/Right Movement)

To enable movement of our robotic arm from left to right, we were planning on utilizing a belt and pulley system, powered by a stepper motor, to move the "platform" (likely just a scrap piece of wood) that our robotic arm is attached to. The "tracks" for this movement would be two aluminum rods extending across the width of our "cube."

In our low-fidelity prototype, we used a lego mockup to show what this setup would look like. First we built "tracks" using longer lego pieces as a proxy for the aluminum rods we would use in our real design. We stretched a rubber band around two wheels attached to the ends of these tracks (a proxy for the belt and pulley system we would utilize) and tied a little knot onto the rubber band — this knot was a proxy for the platform our robotic arm would attach to in the real design — and connected our simplified robotic arm to that knot. We attached an arm to one of the wheels so we could manually turn it and facilitate horizontal movement across the "tracks," much as the actual stepper motor would turn a gear to facilitate movement along the aluminum tracks.

We were quite happy with how this design turned out and expect to implement something very similar, albeit powered by a stepper motor and using aluminum rods for support as well, in our final design.

3. Y-Axis Tracks (Forward/Backward Movement)

As with the x-axis, we had planned to use a belt and pulley system combined with a stepper motor to enable forward/backward movement of our robotic arm. In our actual design, we would have used aluminum rods as the "tracks" to support this movement. The x-axis tracks would be connected to this one perpendicularly via wooden attachments to allow our robotic arm to move across an entire 2D plane.

In our low fidelity prototype, we simplified our design by creating a mockup of these tracks using cardboard. We glued thin (length-wise) cardboard pieces spanning the y-axis of our cube to the left and right walls. This would support the weight of our lego contraption simulating the aluminum rods for x-axis movement. Rather than build another belt and pulley system, we chose to just manually move the x-axis tracks by pushing the lego piece forward/backward to show how movement along the y-axis would work.

We were similarly happy with how this design turned out and expect to implement something very similar in our final design.

In the final design we will implement the y-axis movement through a stepper motor, unlike the prototype, where we manually changed the location of the robotic arm structure.

4. Height-Extendable Robotic Arm (Revised to Robotic Arm + Z-Axis Tracks)

Our original design for the robotic arm, which as explained above would be attached to our system of tracks to facilitate movement along the x and y axis, was going to include a motor to make the length of our arm adjustable. The arm itself would have been a relatively simple metal arm.

We simulated this design using legos as well, using a system of manually extendable/retractable rods to show how the length of the arm would change.

After discussing this prototype with the TAs, we looked into an example of a 3D printer which uses an alternative mechanism of movement. We were inspired to use a third set of aluminum "tracks" for the z-axis movement that would allow our robotic segment to adjust its height up and down. The difference lies within adjusting the length of the robotic segment to move up and down in the z-axis versus moving the whole structure, that also includes the robotic segment, up and down. After carefully evaluating the two possibilities, we ultimately decided to go with the latter, as there are a few advantages, described below, to the second prototype where we would move the whole structure across the z-axis aluminum tracks.

With the robotic segment shifting its length, we would have needed a separate motor on the "arm" itself to allow the automatic adjustment. The arm is a lightweight segment that might have not been sturdy enough to hold the motor and perform the movement. However, with the tracks allowing for the movement, the motor can be anywhere else inside the box, and not be on the robotic "arm" segment. This would allow the robotic "arm" segment to be less heavy, which is a serious consideration given that it will be hanging from the "ceiling" of our cube and we need it not to fall.

Additionally, since at this point we had already planned to allow our robotic "arm" segment to rotate (a decision that came out of the revised ball joint) to allow for a better cleaning, making the arm segment itself height adjustable would have required a separate second motor. Two motors at the top of the"arm" segment would be much harder to implement. With the new prototype, utilizing the z-axis tracks, we would only have one motor at the top of the arm that gives it the spinning functionality. Having a separate z-axis is more intuitive and easier to control from a controller.

5. Ball Joint (Revised)

We had initially planned to use a ball joint at the end of our robotic arm to allow our rotating cleaning disk to flexibly reach all crevices in whatever structure it would be cleaning.

In our prototype, however, we had trouble making a proxy for this design; we were only able to show how our cleaning disk, attached to the robotic arm, could flexibly move left and right, much as a mop joint can. We did not have tools at our disposal to make something like a ball joint, which would allow flexible movement in all directions.

After consulting with a TA, this actually inspired us to consider a different design. We decided to allow for movement of the "arm" segment in all 360 degrees (the "spinning" movement described in the previous section), so that combined with the left and right flexibility of the joint we would be able to achieve the same impact and reach as a ball joint would have allowed us. Ultimately, we have implemented the same functionality but with a different method. Instead of having a flexible ball joint, we decided to allow for the arm to spin and for the "mop" to be flexible only in the left and right directions, which is what we achieved in our prototype.

6. Rotating Cleaning Disk

To enable rotation of our cleaning disk (with the mop attachment at the bottom), we had planned to add a small motor to the bottom of our robotic arm, beneath the ball joint, to allow for the disk to spin and more effectively clean.

We were able to simulate this design pretty easily using legos in our prototype. We attached a gear to the bottom of our "ball joint" contraption using a lego piece that allowed it to spin freely.

We had initially planned for the robotic "arm" segment to spin together with the "mop" at the end. However, since we changed our design to allow the arm to spin instead of the ball joint, for the maximum flexibility and reach especially for the case of curved objects (bowls), we decided to separate the mop spinning functionality. Having the mop spin separately allows for more effective cleaning. The mop attachment is after all the central cleaning function, as the rest of the functions and segments simply ensure the reach of the object within the cube, while the spinning ensures that objects are properly cleaned.

7. Controller

Our final design will have a wire-connected controller with separate buttons for each functionality. Since our cleaning cube will allow manual control over the functions, we need a controller. Initially, we had two ideas for the controller – (1) to either make a separate controller app that would work remotely and would control the cube's robotic "arm" segment through the 3 axes remotely through the app, or (2) to have a computer keyboard that would use some of the keys to allow for the control.

However, after discussing these ideas with the TAs, we came to the conclusion of making the controller wired-connected rather than use a computer keyboard. This would make the design more robust, and the controller more intuitive, since it would have fewer keys and would afford only for the cube functionality.

We also prototyped two wire-connected controllers. Prototype one for the controller was using a flat board with buttons for each functionality (up/down, left/right, movement across the z-axis, spinning of the sponge, and the spinning of the "arm").

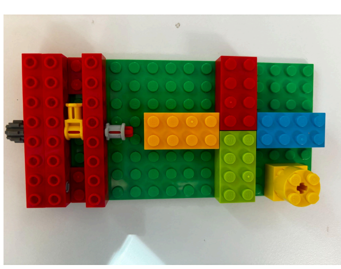

Image 1: Prototype 1 for the controller

However, we noticed that representing buttons that would map to the 3D directions (x, y, and z axis) on a 2D flat surface and making it intuitive enough for a child to be able to use it was quite challenging. Therefore, we prototyped our second controller.

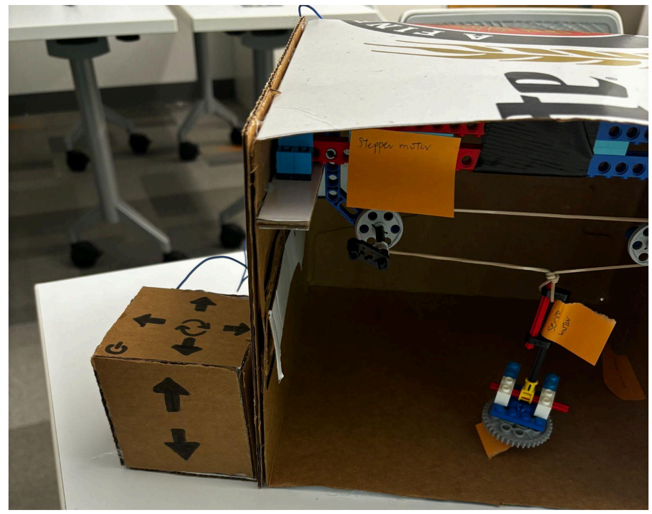

Image 2: Prototype 2 for the controller

Our second prototype for the controller is a smaller scale box (the cardboard box in the image 2) with buttons corresponding to each direction that the structure with the cleaning "arm" segment will move, if the button is pressed. Hence, we see the buttons for up and down across the z-axis on one of the sides of the cardboard prototype, and buttons for left and right, and movement further into the box across the x and y axis on the other side of the box. Additionally, we have indicated the spin button with the spinning arrows sign to spin the robotic "arm" in order to reach curved objects and adjust the "arm's" orientation. We also have a "power on" button, represented by the universal sign, which when clicked turns either on or off the spinning of the sponge.

While comparing the two prototypes for the controller, we concluded that the box prototype was more intuitive in showing exactly how the controls would map to the directions of the movements of the "arm." Hence, we decided to proceed with the second prototype.

PRIORITY RANKING OF FEATURES

<u>Basic Features, ranked in order of importance</u>

1. 3D range of the cleaning arm (x, y, and z-axis separately enabled)
2. User-input-based controller for motion of the robotic arm
3. Spinning disk and arm motion, joint that will allow it to clean at an angle as required for curved surfaces
4. Attachment/detachment mechanism for different cloth materials on the spinning disk

<u>Additional Features (Optional)</u>

- Mechanism to dispense/spray water on surface to be cleaned
- Sensors, such as ultrared sensors at the bottom of the box to detect dirt
- Provided the time, we would want to try and allow users to control the movement of the arm via an app; we would allow them to control movements along the x, y, and z axis

ADDENDUM

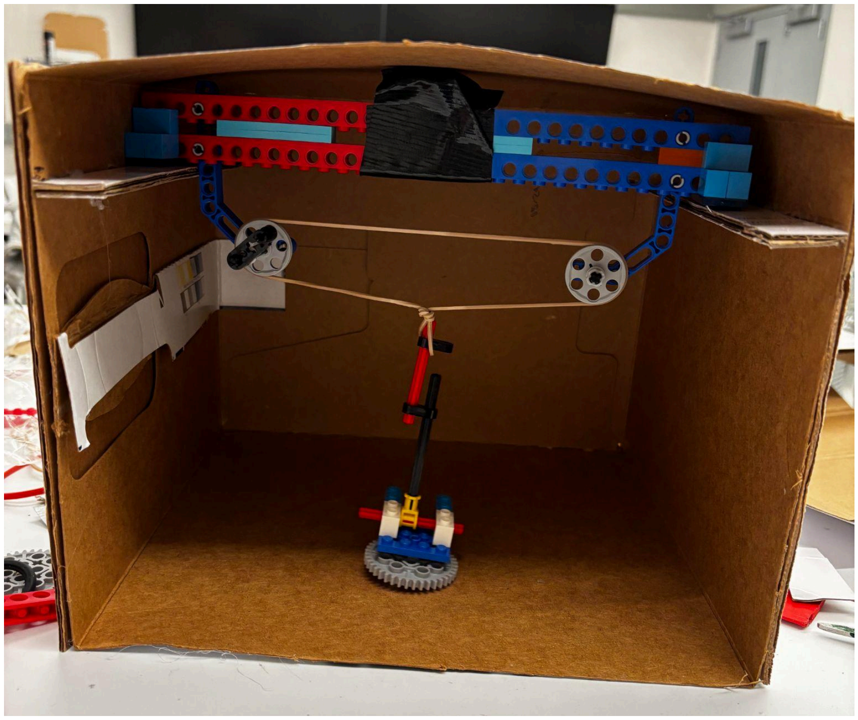

Image 3: Initial design of the cube

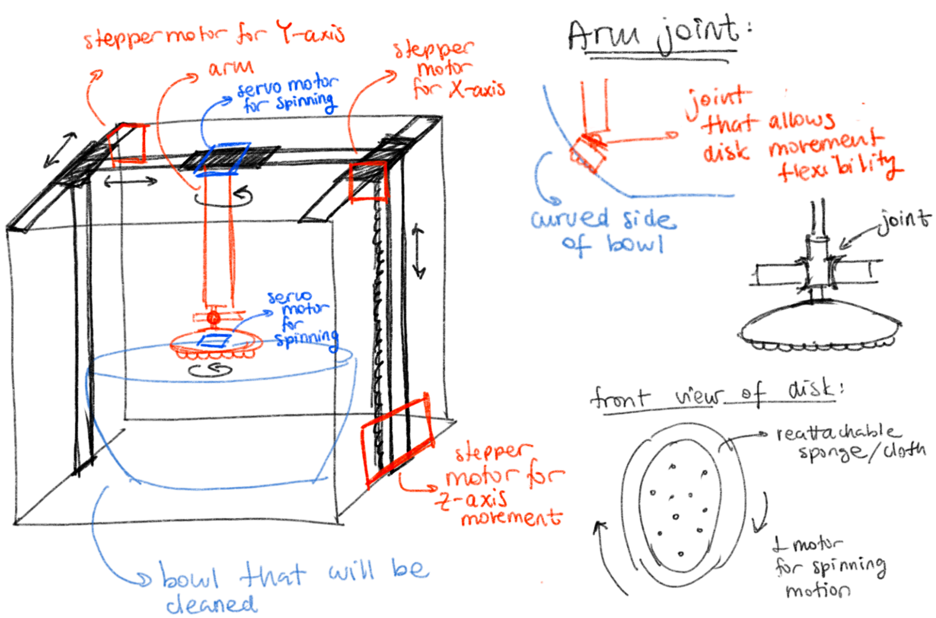

Image 4: Final revised design of the cube