Converting Rotational Motion to Vertical Motion

Introduction:

In Botball the main goal of any robot is to manipulate game pieces in a 3d space in order to score the greatest amount of points possible. When it comes to motion in the x and y axis, the robot's base (the I-create or the “Link”) is able to simply drive using motors. However, when it comes to motion in the z axis, or vertical motion, some system of motors or servos is required. This paper will review some common methods of producing vertical motion using rotational force provided by motors and servos.

Characterization:

For this paper, an arm will be any device that is mounted on a robot to move pieces in a vertical manner. The base of the arm is the entire structure needed to support it, and the range of motion is the area where the arm's end is able to reach. An important factor in any arm design is the path or shape of its range of motion as well as its end orientation.

Overview of Arm Types:

During my time participating in Botball, I have mainly witnessed three types of arms. Simple rotating beams, shifting parallelogram linkages, and two part rotating beams. All of these arms use beams mounted at a fixed rotating point to move the tip of the arm vertically. These types of arms are relatively simple to build, and do not require a large structure or precise tolerances to function well. In addition, the size of the supporting structure is small, and their range of motion is much larger than the structure. This is beneficial when trying to fit the robot within the starting box as the range of motion is not limited by the size of the structure.

In addition, I would like to propose two additional arm designs that are less frequently seen, but which I think offer some distinct advantages when compared to more traditional arm designs. These are the pulley, and rack and pinion designs. These arms are unique because they are able to produce perfectly linear motion. While not always needed, perfectly linear motion can be useful for tasks that require precision when lifting or dropping an object. The main drawback for these arms are their complexity, as they each require more components to work in coordination to be used effectively. In addition, their range of motion is limited to the size of their base structure.

Arm Design Review:

Simple Rotating Arm:

This is one of the most commonly seen arm types in Botball. It uses a beam which rotates around a pivot, mounted on the robot's base. The angle of the arm is controlled by a motor or servo. The vertical motion of this design is produced by the change in height of the tip as the arm moves along a circular path. The arm’s range of motion is a circle around the pivot point, a distance equal to the arms length.

Pros:

The main advantage of the simple rotating arm is its simplicity. At its most basic, it can be built with a single motor/servo and a single lego beam. Due to this simplicity, it can easily be added to a robot for simple tasks such as flicking a switch or knocking down a game board piece. In addition, if mounted high enough, the simple rotating arm's range of motion can reach nearly 360 degrees in front, above, and behind the robot.

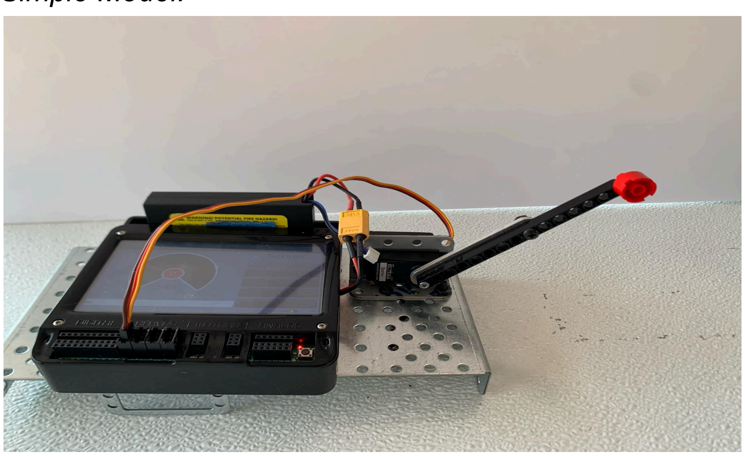
Cons:

Due to the simple rotating arms simplicity, it struggles to complete more complex tasks. Because the vertical motion is based on the height within its position in a circle, at different angles, it has varying vertical force. Another issue of its strictly circular path is that the force of gravity opposing the motor/servos movement will vary. For example, when the arm is parallel to the ground, the force of the arm's weight is perpendicular to the arm, and therefore the highest. However, when the arm is at 90 degrees, or perpendicular to the ground, the force of gravity is negligible in terms of rotational force on the motor/servo. Gravity is counteracted by the arm and its structure itself. Due to this varying resistance on the motor/servo, the simple rotating arm is limited in its ability to lift larger objects or have complex components mounted at its end. Another issue with the simple rotating arm is that the end of the arm's orientation is locked to being equal to the entire arms angle. This lack of control over the end of the arm's orientation means that it is typically relegated to being used to pick up objects whose orientation is not important, such as poms.

Specific Botball Applications:

Our team has used several simple rotating arms on our robots. During the 2022 regional tournament we used a simple rotating arm with a scoop to pick up poms. During our 2023 regional tournament we used this mechanism with a claw to pick up and drop noodles. This was an ideal task for the simple rotating arm because the noodles were relatively light, and could be dropped in one area. Also, their orientation was not important for the task.

Simple Model:



<u>Shifting Parallelogram:</u>

The shifting parallelogram is similar to the simple rotating arm in the sense that it uses a circular path to produce vertical motion. It differs from the simple rotating arm because it adds another beam equal in length to the rotating arm, which is mounted parallel to the rotating arm. This transforms the entire arm into a parallelogram. Because each corner is a rotating joint, it is able to shift into different parallelograms. Due to the addition of this second arm, the end of the arm is always parallel with the structure of the shifting parallelogram.

Pros:

The main benefit of the shifting parallelogram is its ability to shift the end's position without affecting its orientation. Because its end orientation does not change, the shifting parallelogram is able to manipulate objects whose orientation is important,such as lifting noodles and stacking cubes. When combined with careful movement of the robot's base, the horizontal component of its circular path can be counteracted, allowing the tip to move straight up without rotation. Also, because it has another parallel bar reaching toward the tip, the shifting parallelogram can be sturdier than a simple rotating arm.

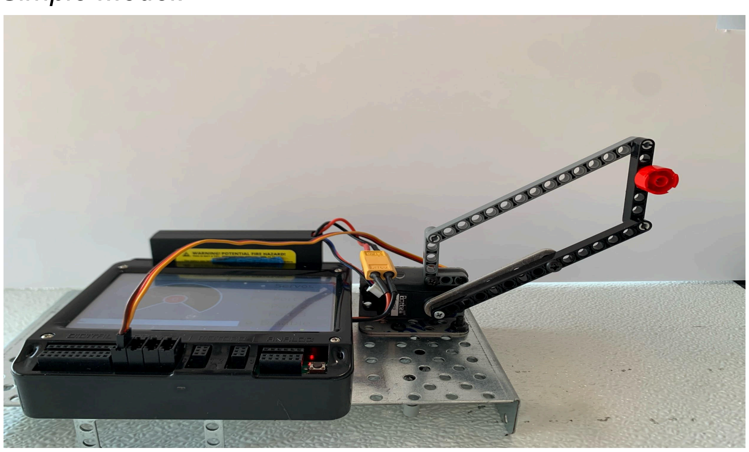
Cons:

Just like the simple rotating arm, the force on the motor/servo varies throughout the shifting parallelogram path, meaning the motor/servo is more likely to degrade or break with use. In addition, it requires much more material to build compared to the simple rotating arm. Due to its nature as a parallelogram, its range of motion is limited to a maximum of 180 degrees before it contacts its own structure.

Specific Botball Applications:

During our 2023 regional tournament, we used a large shifting parallelogram mounted on an i-create to lift and drop pool noodles on poles. In combination with a touch sensor mounted at the top, we were able to achieve consistency using the i-create base to lift up noodles off a pole. This was an ideal task for the shifting parallelogram because in order to drop the noodles on the pole, they needed to be perfectly straight up.

Simple Model:



<u>Two Part Rotating Arm:</u>

The two part rotating arm is a more complex version of the simple rotating arm. Instead of being one fixed arm, it is segmented into two pieces by having a joint in the middle.

Pros:

Adding another segment to a simple rotating arm can solve many issues of the simple rotating arm. By having the second joint rotate in the opposite direction as the base joint, similar to the shifting parallelogram, the orientation of the end can be fixed. In addition, because the middle joint is independently controllable, the maximum range of motion changes from a single line in a circle, to a whole region. The only limit on the range of motion is the length of both arm segments combined. In addition, using careful trigonometry, a perfectly linear path can be achieved for the end of the arm.

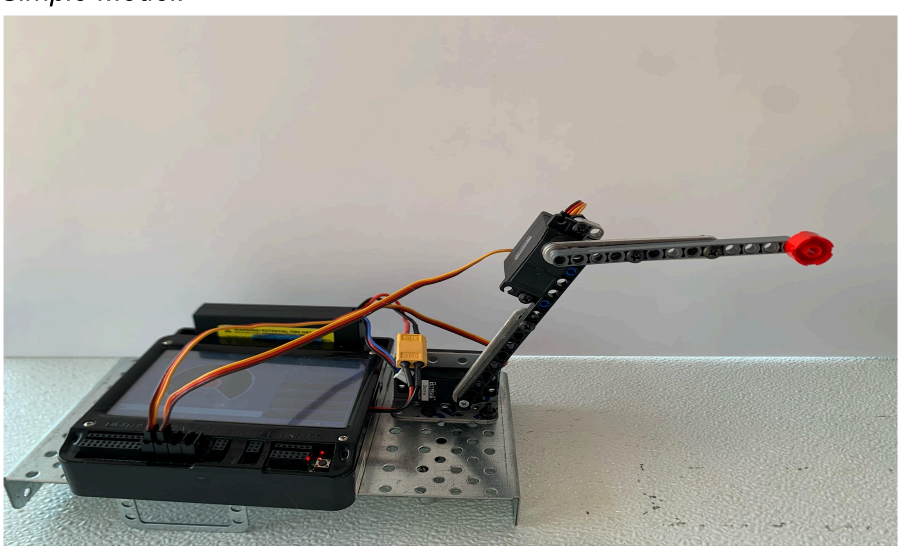
Cons:

The main problem with the two part rotating arm is the added weight and complexity of the middle joint. In order for the arm to still be physically robust, the middle joint needs to be carefully built. The middle joint requires an additional motor/servo, which is costly given the limited numbers of motors and servos available. In addition, the arm cannot both produce linear motion and maintain the end’s orientation at the same time. Also, when it comes to moving the arm’s end in a linear path, coding requires trigonometry, which adds complexity and makes it more labor intensive compared to a simple rotating arm.

Specific Botball Applications:

During our team's 2022 season, we used a two part rotating arm to grab Botguy and cubes. This was an ideal task for the two part rotating arm. We needed to be able to bend the middle joint in order to grab Botguy around the middle, but also to drop him at a precise angle.

Simple Model:



<u>Pulley:</u>

A pulley is a system of a winch, a rail, and a cart. The cart moves back and forth along the rail, and its position is controlled by a string. The string is wound around a winch, which is controlled by a motor/servo. The string is looped around a pulley at the top of the track, and is used to pull up the cart. By releasing string, the cart will fall down due to gravity. The pulley's range of motion is simply the line along the rail that the cart is able to reach. Depending on the radius of the winch, the builder is able to decide whether to prioritize speed or precision. If the radius of the pulley is larger, the cart will move faster but be less consistent. It will also lift less weight. If the pulley's radius is smaller, the pulley will move slower, but be much more precise, and able to lift large objects.

Pros:

The main benefit of the pulley is its ability to move in a perfectly linear path. If the rail is designed well, the pulley cart can have almost no variability in the x and z directions. The rail being vertical also means that the horizontal footprint of the pulley system is relatively small. In addition, the force from gravity acting on a pulley’s motor or servo stays the same regardless of the pulley's position on the track, which helps reduce wear.

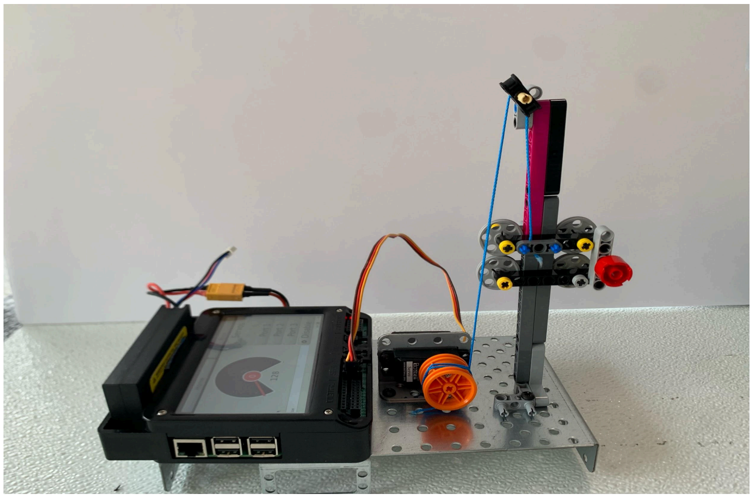
Cons:

A problem with the pulley system is its range of motion. Motion is dictated by the size of its rail, so the cart is unable to reach any position above the robot's starting box size. This height issue severely limits the number of tasks the pulley is useful for. In addition, outside of being sturdy, the track and cart need to be designed in a way that ensures the cart is able to move smoothly along the track. Any friction of the cart will limit the maximum load the motor/servo is able to lift. In addition, mounting a pulley at the top of the rail only offers powered movement upward. Any movement down relies on gravity. In order to fix this you could add another pulley to the bottom of the rail, and pull the cart down. This, however, adds complexity to an already complex system. Also, the maximum amount of string allowed may make this impossible. In addition, depending on the string used, there can be some inaccuracy caused by the string physically stretching.

Specific Botball Applications:

Our team used a pulley during the 2023 GCER tournament in order to lift a ring along a complex PVC pipe path. The PVC pipe path had sharp turns and straight vertical sections. The pulley was well suited for this task because it offered good precision, as well as consistency in moving the ring upwards. In addition, the area the robot had to maneuver for this task was in a corner, so the pulley's smaller horizontal size was also a benefit.

Simple Model:



<u>Rack and Pinion:</u>

The rack and pinion is similar to the pulley in the sense that it uses a rail system. However, instead of string, the rack and pinion uses gears to move the arm's end. The "rack" is a line of gear teeth, and the "pinion" is a gear. When the gear is rotated, the rack moves in relation to the pinion. Linear motion can be achieved here either by having the rack be fixed to the robot's base, and moving the pinion up and down, or by mounting the pinion and having it push the rack up and down. In both scenarios, a structure around the pinion is needed, ensuring the end does not move around.

Pros:

Like the pulley, the rack and pinion is able to produce perfectly vertical motion in a somewhat small footprint. However, compared to the pulley, the rack and pinion system has even better precision because there is no issue of the string stretching. By using gears, the only source of inaccuracy would be the tolerances between gear teeth. In addition, the rack and pinion is able to provide powered movement in both directions, as it does not rely on gravity.

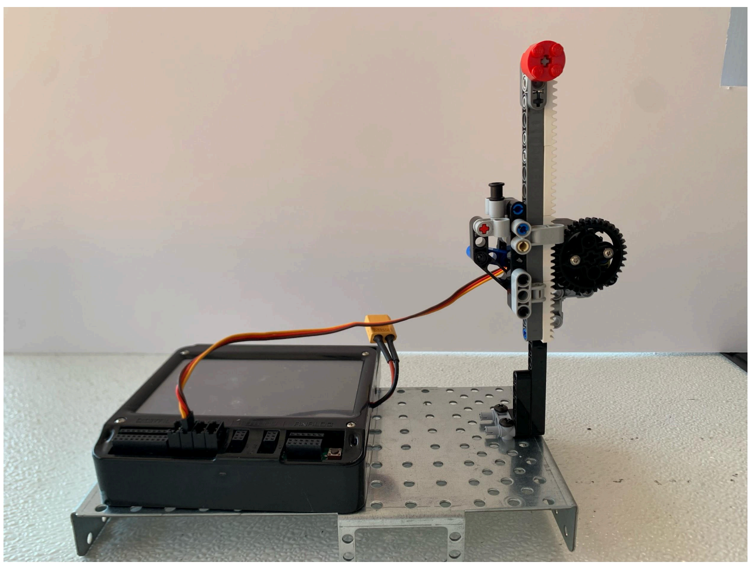
Cons:

Because the rack and pinion relies on the gear rack and the pinion interlocking, the mounting of the pinion to the rack needs to be very precise. Any distance between the rack and pinion will lead to variability. In addition, the main issue with the rack and pinion system is that typically in a kit there will only be a few 1 inch long lego gear racks. This means that for any task that requires a large range of motion, the rack and pinion system will not be an option. In addition, similar to the pulley system, the range of motion of the gear rack cannot be any larger than the size of its rail.

Specific Botball Applications:

Due to the limited number of gear racks, our team has not used the rack and pinion system to manipulate pieces. However, one way we found the rack and pinion system to be very useful was in combination with the linear slide. If you are using a motor in place of a servo, one of the biggest issues is knowing the motor's absolute position. The GMPC counter can be useful when trying to find how much a motor's position has changed, but it does not track absolute position like a servo. By mounting a gear on the motor, and attaching a rack to the gear, the rotational position of the motor can be converted into a linear position. This linear position can be tracked using a linear slide, allowing the motor's absolute position to be tracked. This is particularly useful when the motor is powering a long arm, where knowing the arm's absolute position is necessary.

Simple Model:



Conclusion:

I hope this paper helps illustrate how different arm types have their own strengths and weaknesses, and specific Botball applications. Although popular, the simple rotating arm and the shifting parallelogram are not the only way to obtain vertical motion. In my Botball experience, a vast majority of teams use these two designs. However, I feel that the other three arm designs can be just as, if not more, useful depending on the circumstances. By experimenting with different arm designs, both coder and builders can expand their capabilities. With more experience in different designs, a team is better equipped to solve diverse challenges.