Design Build Test Project

A Report

by

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Introduction

Going into our Design Build Test project, our team came to an agreement to prioritize the reliability and consistency of the device in lieu of achieving a high figure of merit (FoM). We opted for minimal design risks at a lower score, selecting convenient, spherical objects including the ping pong ball, marble, and bouncy ball. We built our devices upward to utilize gravity and avoided relying on heavy electronics for motion, ensuring a low weight and high volume assembly. Each device was built with plans to integrate later, so the assembly's tubing and erection was an afterthought of the design process.

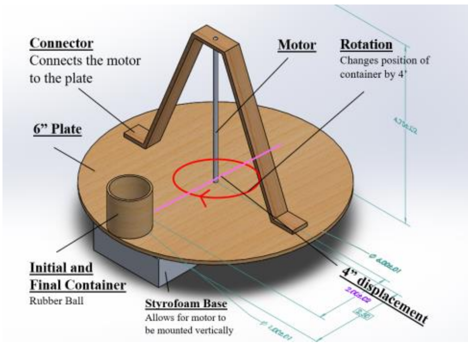

Figure 1. Horizontal Motion Mechanism

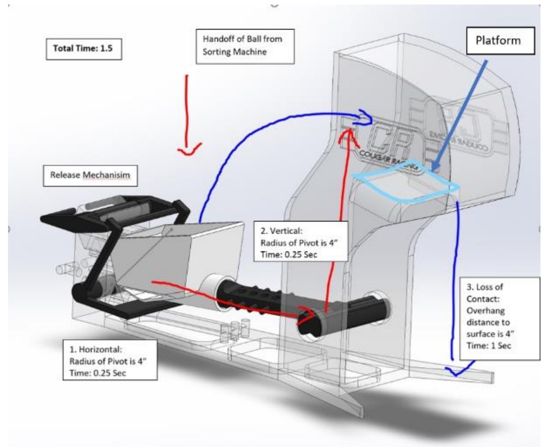

Figure 2. VHL Mechanism

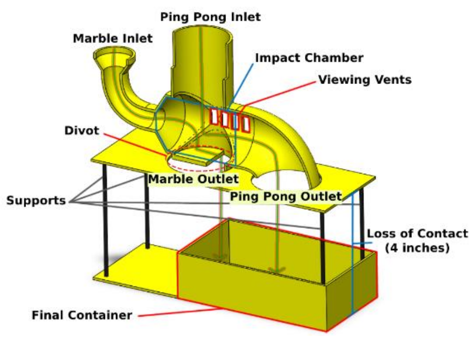

Figure 3. Impact Mechanism

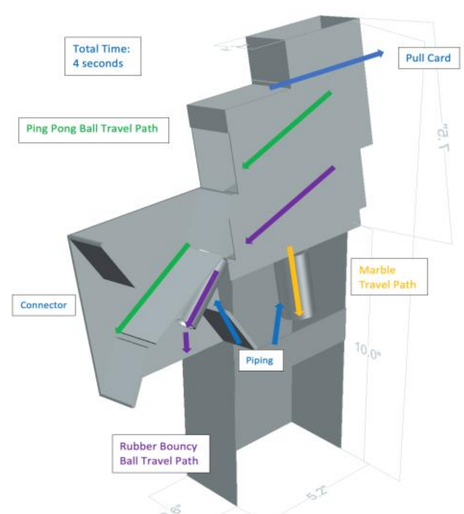

Figure 4. Sorting Mechanism

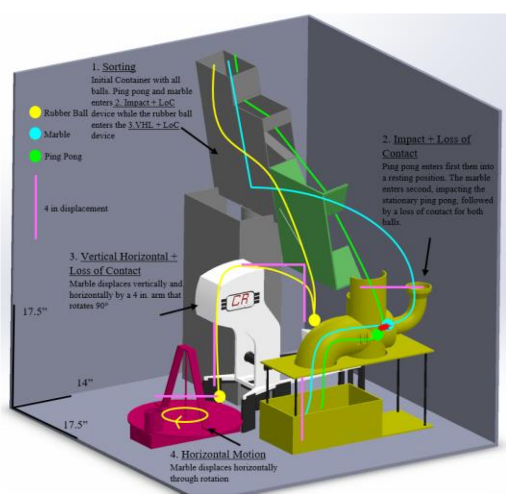

Figure 5. Assembly CAD

Device Description

The assembly occupied a majority of the maximum allotted volume because our team wanted reliable integration rather than the additional points. After construction, the assembly had a length, width, and height of 14, 17.5, and 17.5 inches (Figure 5) respectively. The assembly was approximately 2.5 lbs because each device prioritized light materials for a lower overall weight. All devices were glued to a base to improve the reliability by making the alignment of each device consistent. Each successful run of the assembly was about 32 seconds, with a majority of the time allocated to the horizontal motion mechanism's spins, earning an overwhelming majority of the expected FoM. There are two connector links – the Sorting Mechanism to the Impact Mechanism and Vertical, Horizontal, Loss of Contact (VHL) mechanism – to earn more points.

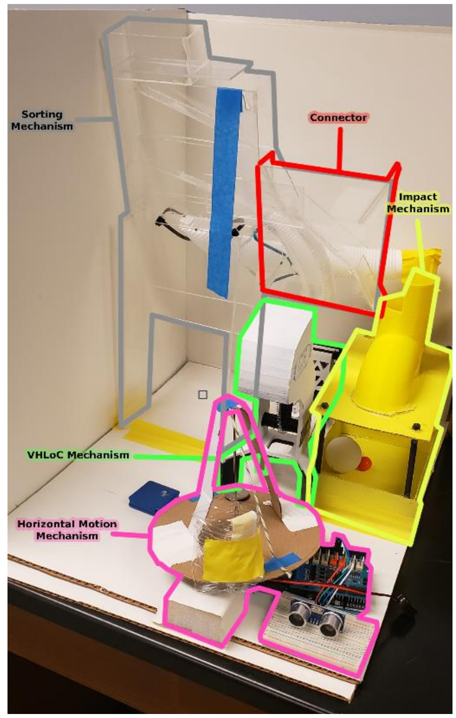

Figure 6. Final Assembly

Sorting Mechanism comes first in the device's function, so we positioned the initial container on top of it. The height allowed the device to maximize the advantage of gravity. A pull card was used to drop the objects into the mechanism. A series of inclines then sorted the balls by size. The mechanism was placed at a 10 degree angle upon the base to eliminate the chance of the marble being improperly sorted. The ping pong ball was caught first by the inclines where it then exited at the uppermost opening and made its way to the impact mechanism across the connector via a bridge. The rubber bouncy ball was sorted next and also sent to the connector where a pipe guided the ball towards the vertical motion mechanism. Lastly, the marble was dropped to the bottom of the mechanism where it was taken via a pipe to the impact mechanism. The Sorting Mechanism consistently had the three objects ending at their expected final destination, which are all 4 inches apart. The Sorting Mechanism utilizes a stand to elevate it to an appropriate height. The stand, Sorting Mechanism, and pull card were made from polycarbonate and utilized a polycarbonate glue for adhesion. Polypropylene piping was adhered to the connector using the same glue and adjusted to the bottom of the Sorting Mechanism using zip ties. Polycarbonate was chosen due to its rigidity and ability to provide a clear view of the sorting function.

The impact mechanism was composed of a 3D printed main component using polylactic acid (PLA) on top of a cardboard support system with chopsticks as supports. These materials were chosen because they are light, so the weight of the impact mechanism was just under 8 ounces. The PLA component housed the impact chamber where the ping pong ball would get stuck in a divot then get hit by the marble, falling 4 inches downward into the final container. Viewing vents looked into the impact chamber so the entire process could be seen. To address the need for limited electronics, the ping pong ball would fall into the divot and get stuck and the marble would follow shortly after, relying on longer tubing to arrive after the ping pong ball came to rest. The lack of electronics made this process fail 10% of the time to variable timing or the ping pong ball bouncing inadequately, trading off some reliability for the need of low weight. The divot was angled 5 degrees down from the horizontal to guarantee the marble falls through its outlet, and each object successfully arrived at the final container on every test run so the part would never disqualify. The inlets on the impact part were printed with small tolerances to dock tubes tightly when constructing the assembly.

In the VHL mechanism, the carriage was pulled using a spring held at a constant force large enough to lift the object around the pivot. This arm was held back in its horizontal position to await the object's entry into the carriage by the release mechanism. Once the release mechanism was triggered, the arm could freely move in the direction the spring pulled. The object reached the upper position after traveling 90 degrees around the pivot, then rolled down the platform four inches from the surface of the next device's carriage. This device met the conditions of elevating the object 4 inches, horizontally moving the object 4 inches, and dropping the object with a loss of contact of 4 inches. The material of choice was PLA. This was the material of choice for manufacturing utilizing 3d printing technologies. Fused Deposition Modeling was the specific method of additive manufacturing utilized. The assembly was all tight-fitting joints where needed and loose fitting where a free pivot was required. The assembled dimensions of the mechanism were a length of 9.9 inches, height of 7.2 inches, and width of 3.9 inches

The reliability and consistency priority developed a core idea of designing a device similar to a carousel for horizontal motion conditions. The final design had the initial and final container 2.5 inches away from the center of the 6 inch rotating plate. The plate, connected to a motor, would rotate for 15 seconds (~20 rotations) when a hand was within 7 centimeters range of the ultrasonic. The ultrasonic and motor are connected to an Arduino Uno powered by a 9V battery. The design prioritized minimizing the length and width since the largest component of the design was the 6 inch diameter plate (6" x 6" x 4.75"). Cardboard and styrofoam materials were used for the structure to compensate for the weight of the battery, motor, and breadboard (7.6 oz.). The materials allowed CAD drawings to be printed and traced onto, allowing precise cutting, bending, and placement. The horizontal motion device consistently maintained a 4 inch. displacement without the rubber ball rolling for every rotation; however, the device's dependability in integration caused its reliability to fail.

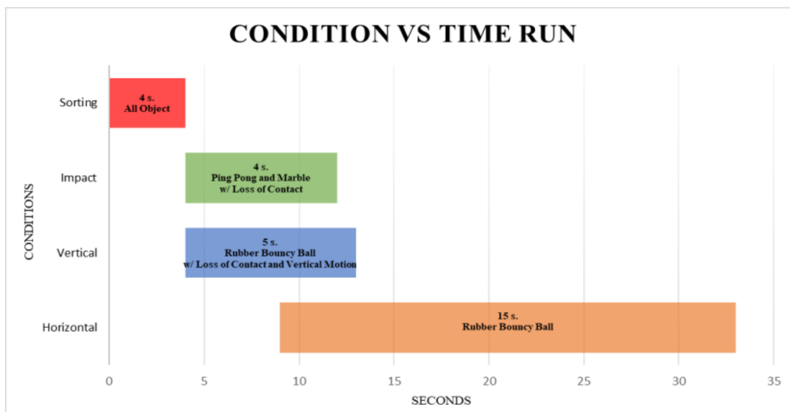

Figure 7. Condition vs Time Run

Testing Results and Figure of Merit

In testing, our objects successfully ran through the Sorting Mechanism. The Impact Mechanism completed a successful impact between the ping pong ball and the marble. The bouncy ball went from the Sorting Mechanism into the VHL Mechanism. Upon contact, the release mechanism was triggered to release the spring-loaded arm to articulate horizontally 4 inches and vertically 4 inches concluding with rolling the bouncy ball off a ledge 4 inches above the next device's carriage. However, unexpectedly the bouncy ball missed its final container in the horizontal motion device. This was because of the instability of the device's initial container position, resulting in misalignment with the loss of contact drop from the VHL Mechanism. Our device performed to the consistency of seven successful attempts out of ten total runs which was close to our initial goal of 90% successful runs.

Table 1. Figure of Merit Data

Device	Expected FoM	Final Run 1 FoM	Final Run 2 FoM
Sorting	17.5	17.5	17.5
Impact	40	40	40
VHL	62.5	45	45

Horizontal	900	DQ	DQ
Connector	10	10	10
Weight/Volume	11.67	11.67	11.67
TOTAL	1029	129.17	129.17

Results Discussion

Overall, we achieved a 75% success rate with each final run since only the Sorting, Impact and VHL Mechanisms functioned as intended along with their extra conditions. Within the two final runs, deviation from intended function came at the fault of the rubber bouncy ball not falling successfully into the final container of the Horizontal Motion Mechanism. The point of failure was the misalignment between the VHL and Horizontal Motion Mechanism. When the 9V battery was connected to the Arduino Uno, it caused the initial position of the motor and the initial container to misalign between two mechanisms resulting in DQ of the Horizontal Motion Mechanism. The point of failure also resulted in the VHL Mechanism not achieving its second condition of loss of contact from the drop of the VHL Mechanism to the container of the Horizontal Motion Mechanism.

Recommendations

The foremost recommendation to improve the design is to refine the integration of devices into the assembly. The transition of objects between devices was not optimized and resulted in the bouncy ball not reaching the final container in the Horizontal Motion Mechanism, so the assembly should have been created earlier to get permanent connections between devices rather than flimsy tubing that required alignment and set-up before initiation. The tubes created uncertainty and randomness, combining the devices with rigid paths would improve the consistency of the assembly. Relying on gravity with no electronics led to a lower score with the added risks of no control beyond initiation. Electronics would have been more beneficial and feasible within the weight limit, allowing for more consistently successful runs. Electronics may increase the risk of failure which can be reduced with the implementation of physical validation throughout the project's timeline and better communication and cooperation. Electronics would have eliminated variables like the ping pong ball not coming to rest before being hit with the marble in the Impact Mechanism.

Conclusions

Our priority of consistency and reliability can be seen with the devices that accomplished their conditions, the Sorting, Impact and VHL Mechanism. Those that attained their expected FoM did rely solely on gravity and no electronics, while the Horizontal Motion Mechanism tried to attain a high FoM resulting in an increased risk of failure. Our device achieved 12.55% of the expected 1029 FoM, earning 129.17 FoM. The consequences of leaving integration as an afterthought caused the point of failure between the VHL and Horizontal Motion Mechanism. The key lesson learned from the DBT project is to stay ahead of the timeline and communicate early on regarding integration.

Appendix

Impact Mechanism Simulation: https://gyazo.com/004c377da256d2b17c5c33c45aba9959