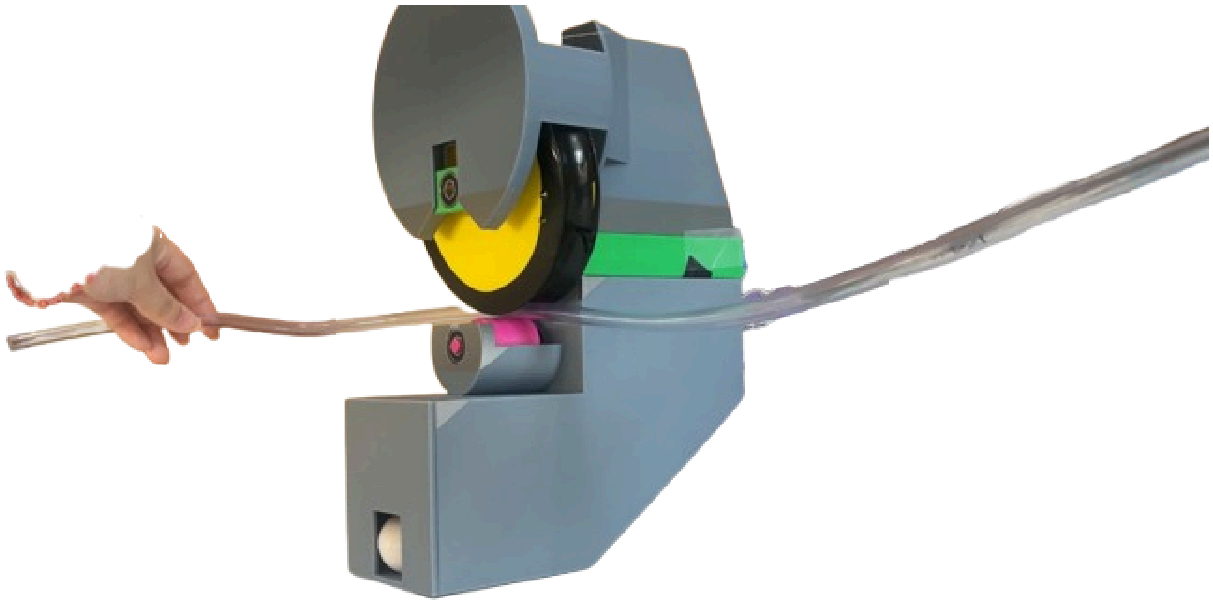
Final Design Report:
Skynet System



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Executive Summary

Project Problem

With assistance from our project partner, Emma Martell, the Director of Child, Teen, and Family Engagement at the Lincoln Park Zoo, we developed a telepresence system to provide users at the Ann and Robert H. Lurie Children's Hospital of Chicago with an interactive virtual tour of the zoo. Previous telepresence efforts, such as a user-controlled robot, were unreliable and did not effectively engage patients, thus highlighting the need for a new solution.

Project Requirements

The purpose of this project was to design a more engaging, reliable, and user-friendly telepresence experience that allows users to explore zoo exhibits remotely. The solution had to be easy for zoo staff to operate while providing an immersive experience for end users.

Research and Development

We spoke with Emma Martell to gather the zoo's history with telepresence challenges and observed both zoo exhibits and the original telepresence robot. We also looked into the needs of users in engagement and assessed current telepresence systems. Using this information, we created and tested some prototypes before finalizing a functional design.

Design Summary

Our final design, Skynet, is a zip-line camera system controlled remotely via a web application. It features:

- A lightweight zip-line-mounted camera vehicle that moves smoothly across exhibits, providing a live video feed.
- Secure and adjustable mounting mechanisms for easy installation and stability.
- A user-friendly web interface allowing patients to control the camera's movement and interact with zoo educators.

Skynet improves upon past attempts at providing a telepresence solution by being portable, easy to install, and highly interactive. All of this promises a more engaging experience for users. Future improvements could potentially include an adjustable camera mount for better viewing angles and additional interactive features to enhance the engagement of users.

Introduction

Hospital patients often face emotional and physical hurdles to varying degrees due to their medical conditions and treatments. Although forms of entertainment, such as a trip to the zoo, could boost their moods and serve as potential distractions, many are unable to leave due to medical restrictions. Such restraints surely limit patients, namely those at the Ann and Robert H. Lurie Children's Hospital of Chicago, from enjoying and learning from the engaging environment of Chicago's Lincoln Park Zoo.

Our project partner, Emma Martell, Director of Child, Teen, and Family Engagement at the Lincoln Park Zoo, has indicated the need for a telepresence solution that lets Lurie Children's Hospital patients virtually tour the zoo. An earlier effort, a user-controlled telepresence robot did allow for some degree of engagement, but faced obstacles, specifically motorboard breakdowns and low interest from its users.

While a live stream or a pre-recorded virtual tour could offer a glimpse of the Lincoln Park Zoo to users at Lurie Children's Hospital, such solutions are very lacking in terms of interactivity. Other options like body cameras or cameras-mounted robots are too bulky and tend to lose the interest of users over time due to the limited movement and poor usability offered. To counter these issues, our team built Skynet – a zip line camera controlled by a vehicle via an external app over the internet. It allows users to experience fun and educational interactivity by making it possible to remotely tour the Lincoln Park Zoo from the hospital. Skynet is perfect for users as it is light and enjoyable to use, while also being easy to maintain by zoo staff. By using a vehicle-controlled zip line, the system enables users to explore animal exhibits at the pace they prefer while engaging with the zoo educators.

This document explains the users as well as the project scope, then details the design ideas and the reasons behind them. We finish with some possible future changes that could improve the system even more.

Users and Requirements

Main Users of the Design

Lurie Children's Hospital Patients: The main users of our design are patients currently receiving care at Lurie Children's Hospital.

Emma Martell: Emma is the Director of Child, Teen, and Family Engagement and our direct point of contact with Lincoln Park Zoo. She manages the telepresence tour program and helps lead tours.

Lincoln Park Zoo Educators: The educators are a group of around 12 trained staff members responsible for leading the telepresence tours and informing Lurie Children's Hospital patients about the animals.

Lincoln Park Zoo Volunteers: The volunteers are a group of around 10 people responsible for informing the educators about which exhibits are engaging, informing the general public about the device and its purpose, and overall ensuring that the telepresence tour remains unobstructed.

Major Requirements

Easily Transported: The device must be easily transported by at most two people, an educator and a volunteer.

Easily Installed/Uninstalled: The learning curve for installing and uninstalling the device must be small to ensure that the general public's viewing experience isn't disrupted and that the touring process is efficient and executed in a timely manner. To achieve such a design, it must have at most 5 fixable components.

Able to Traverse Exhibits: The device must be able to move around the exhibit. It should be able to move at least 2 mph so that the users can track animal movement within the exhibits.

Able to View Exhibits: The device should have a camera with a field of view of at least 170 degrees so that the user can properly view dynamic activity within exhibits.

Engaging: Because the purpose of the telepresence tour is to provide an informative and engaging experience, the device must be interactive, meaning the users must be able to control its movement and the exhibits that it views.

Design Concept and Rationale

The Skynet System (figure x) is composed of a cable system, a drivable zipline vehicle with a camera, and a web app. The purpose of this system is to facilitate telepresence tours of zoos for people unable to be physically present in the zoo itself. The Skynet System features easy-to-install mounts by which a cable can be quickly set up and taken down along walls of any surface. This allows a drivable camera device to move along the perimeter of any room, controlled offsite by a wifi-compatible web app that features a live feed for the end user, as well as the ability for the operators to sketch on said live feed and provide narration for the tour. Further details of each component are provided in the following sections

Cable System - Cable

Description

The cable system is composed of mounts and a detachable cable. In this design, the cable is ¼ inch diameter hollow vinyl tubing (Figure 1).

Figure 1: Cabling made of hollow vinyl tubing

Overall Design Rationale

This material provided abundant advantages to its nylon or steel alternatives. Specifically, its hollow center makes it lightweight and also allows it to deform slightly under pressure, which enhances the grip of our vehicle. However, it is sturdy enough and thick enough to provide the support required. Finally, research revealed that it is one of the most affordable options.

Cable System - Wall Mount

Description

To attach the cable to the wall, a simple triangle mount was designed (Figure 2). This design features a basic truss that distributes weight across the wall and has an adjustable length to accommodate different sized exhibits.

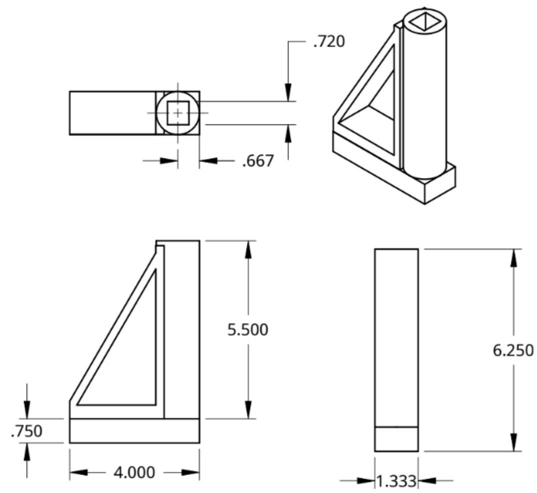

Figure 2: Wall mount with square attachment hole[1]

Overall Design Rationale

The wall side of the mount features a sleeve that slides over a track that is adhered to the wall via command strip. While originally suction, putty, and synched adherence methods were explored, the command strip was chosen as our final design due to budget and time constraints. However, given the sleeve and track design, any of the listed adherence methods could be explored further if placed on the same track, as the mounts designed thus far would be compatible with such a method.

[1] Measurements for dimensioned figures 2-5, 7-11 are in inches.

Cable System - Cable Clamp

Description

The cable clamp is able to hold the cable while the vehicle drives over it. This is done with a flat belly at the bottom (Figure 4) which is compatible with the previously described lower wheel, and a grooved track which starts at the bottom of the cable and curves upward (Figure 3). This design allows the flanged wheel to gradually and smoothly engage with the clamp.

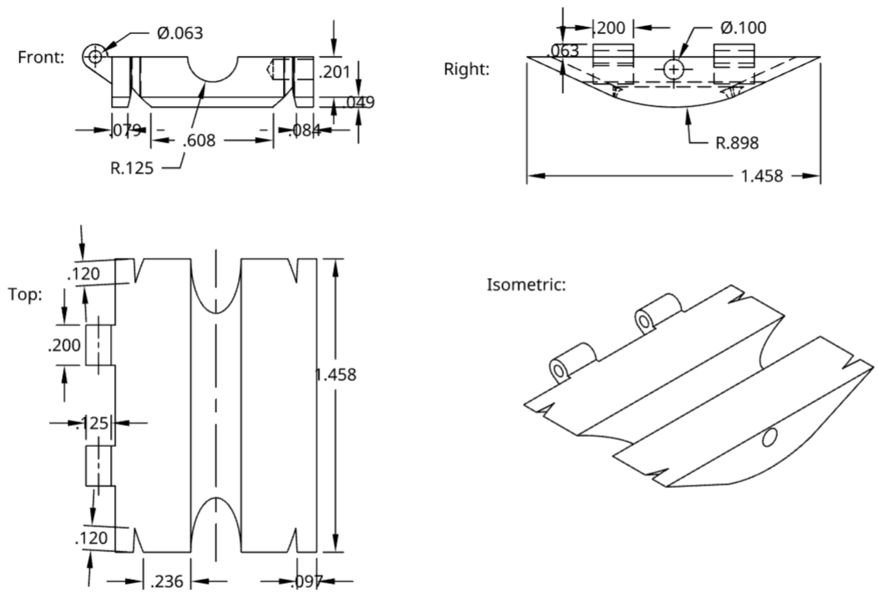

Figure 3: Top hinge part of the clamp[2]

[2] Measurements for dimensioned figures 2-5, 7-11 are in inches.

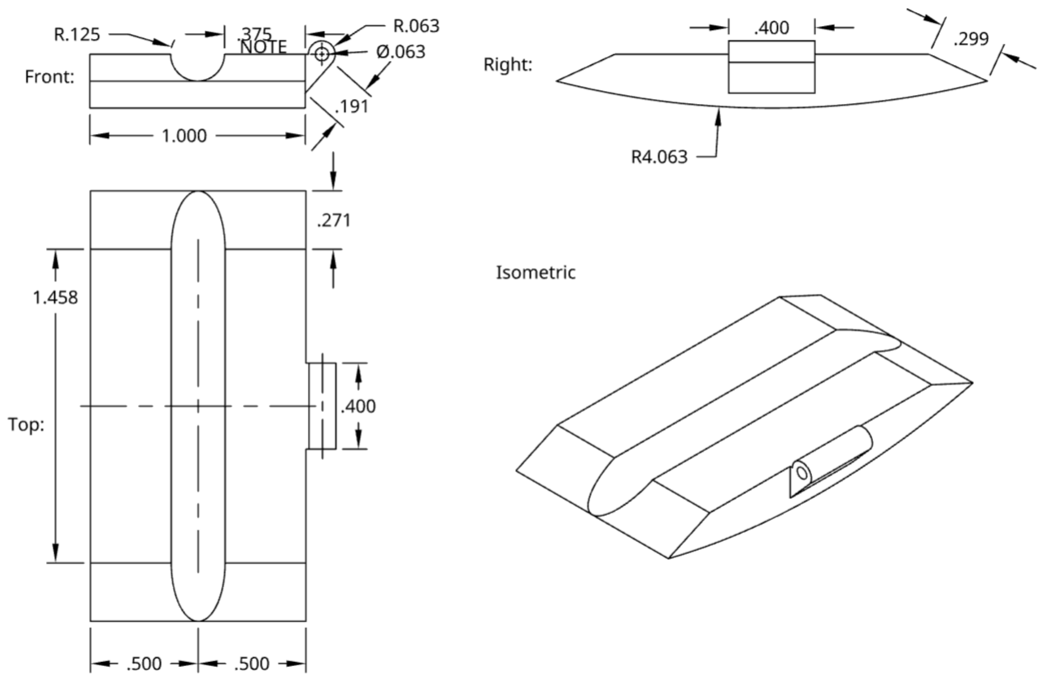

Figure 4: Bottom part of the hinge[3]

Overall Design Rationale

In order to attach the cable to the wall mounts, a specialty clamp was designed that would allow the wheel of the car to travel over it without derailing while still maintaining a strong grip on the cable. This clamp works with the flanges of the wheel to guide the car over it without it derailing.

Drivable Zipline Vehicle - Mechanical Components

Description

The primary component in the Skynet System is the remote-operated zipline vehicle designed. This cable car of sorts has many moving parts, and each will be explained within the following section. The primary, or upper wheel of the vehicle is a simple extruded cylinder of radius 2.2 inches and thickness of 0.75 inches. Additionally, it features a groove in the middle, where the radius reduces down to 2 inches with a parabolic cross-sectional shape. (Figure 5)

[3] Measurements for dimensioned figures 2-5, 7-11 are in inches.

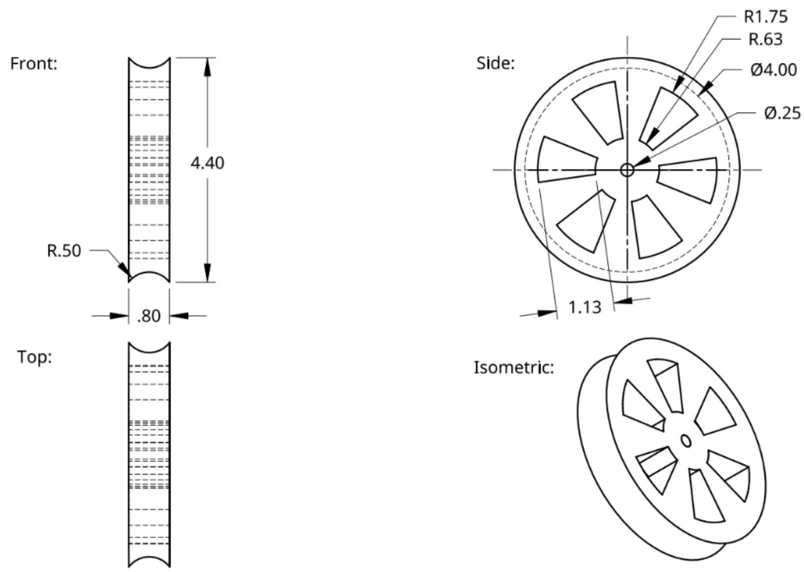

Figure 5: Wheel [4]

The wheel is covered for protection (Figure 6) and is connected to a fixed axle (Figure 7), which is linked to a small motor on one end and fed through a ball bearing on the other.

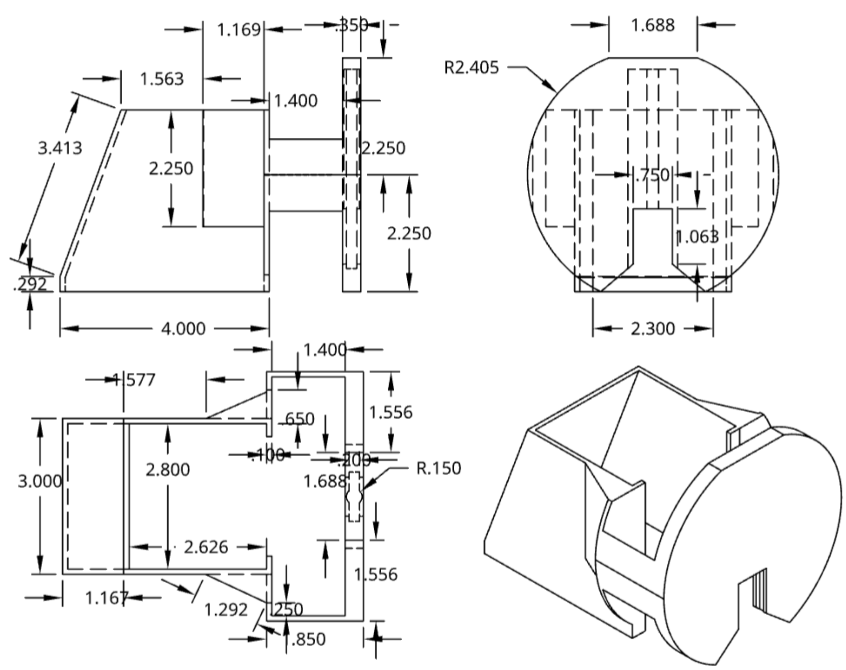

Figure 6: Wheel Housing

[4] Measurements for dimensioned figures 2-7, 8-13 are in inches

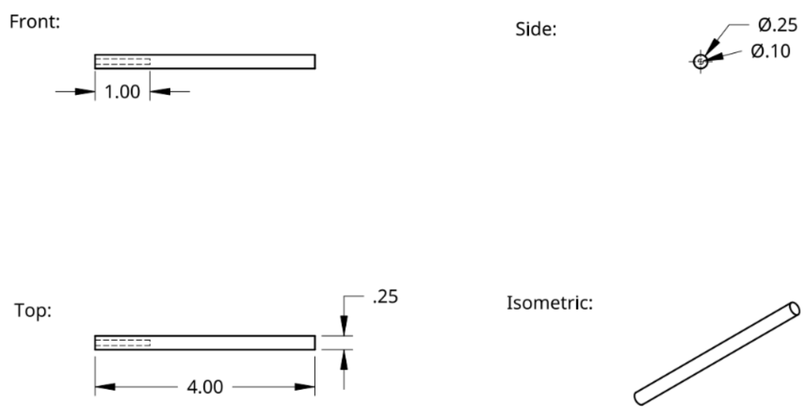

Figure 7: Axle[5]

There is also a suspension system that allows for tolerance within the distance between the primary and secondary wheels. This suspension system consists of 5 sets of springs, four for the motor, and 1 for the bearing. These springs attach through both a bearing cage and a motor cage. The bearing cage is a simple rectangle that slides within a grooved track within the cover of the car. The motor cage is slightly more complex, with rails that are built into the main body of the car. (Figure 9) Both of these have springs that sit between the cage and ceiling of the track. (Figure 8)

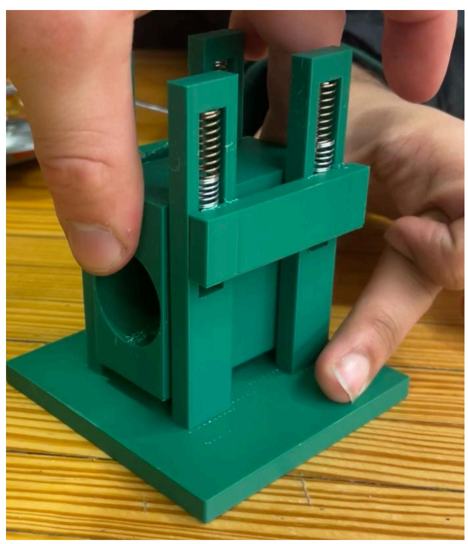

Figure 8: Picture of how the springs sit in the motor cage rails.

[5] Measurements for dimensioned figures 2-7, 8-13 are in inches

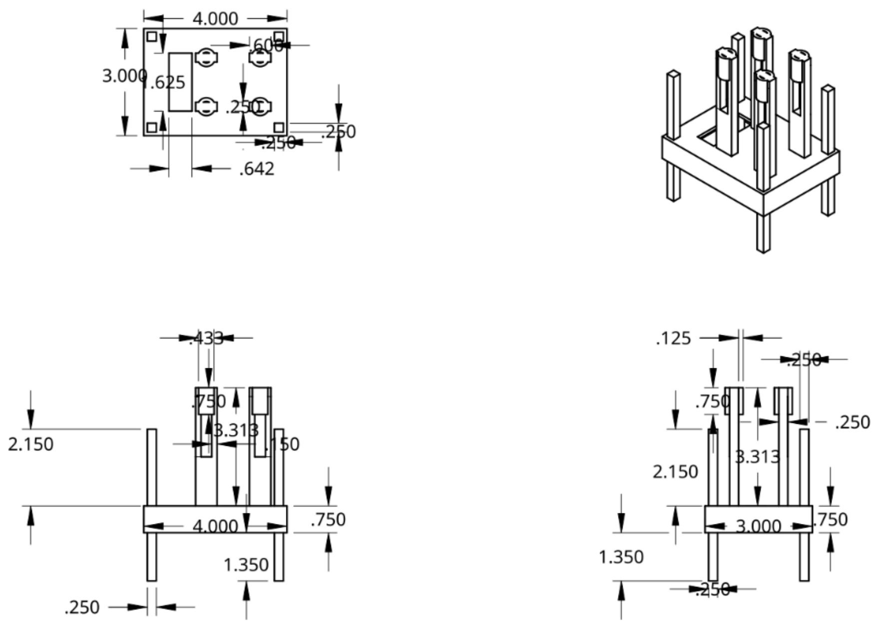

Figure 9: Motor cage rails[6]

The motor cage itself is a simple rectangle with a cylindrical hole of 1 inch diameter through the center to accommodate the motor (Figure 10). It then has arms which sit on the outside to slide within the rails.

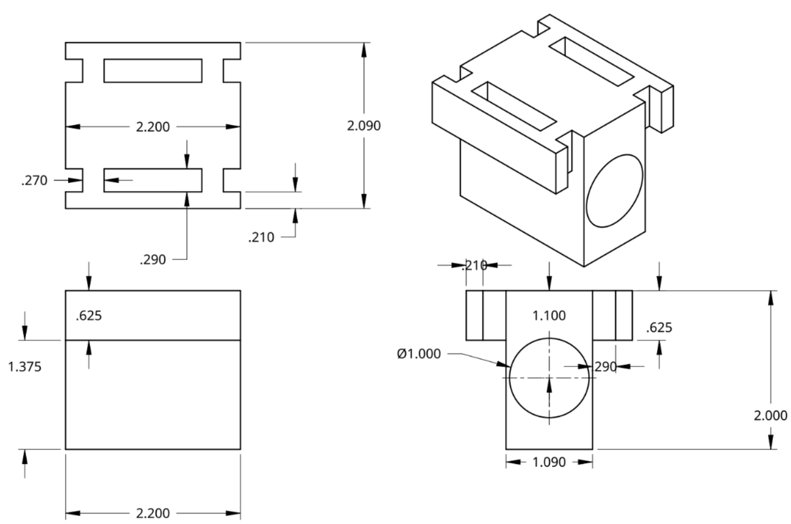

Figure 10: Motor Cage diagram

[6] Measurements for dimensioned figures 2-7, 8-13 are in inches

Beneath this setup lies the lower wheelhouse, which is composed of a lower, unpowered wheel of 1 inch diameter. (Figure 12) This sits within two bearings on either side. (Figure 11) The purpose of this wheel is to provide a surface for the upper wheel to press the cable into for traction while keeping rolling friction at a minimum.

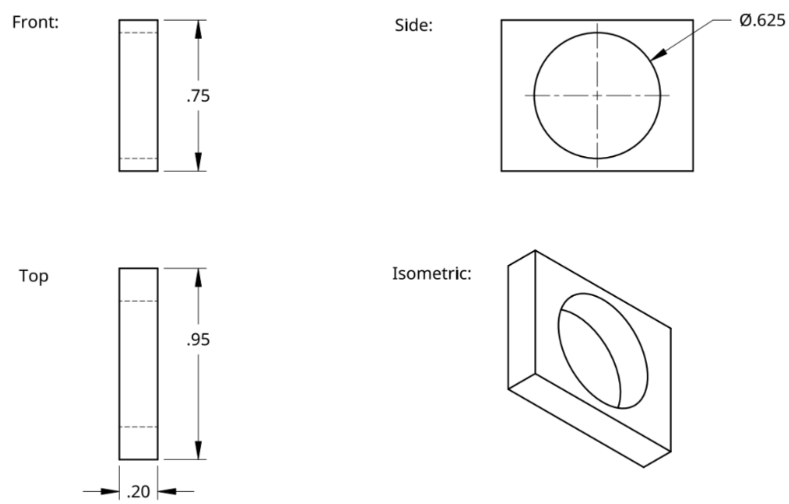

Figure 11: Holder for bearing that supports secondary wheel[7]

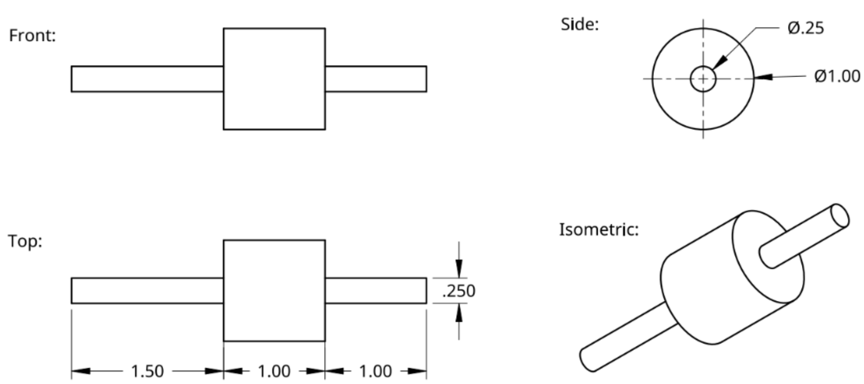

Figure 12: Secondary, unpowered wheel

Beneath this is the main body of the car, (Figure 13) which is a hollow rectangular prism that houses the various electrical components of the car, along with crucially the battery.

[7] Measurements for dimensioned figures 2-7, 8-13 are in inches

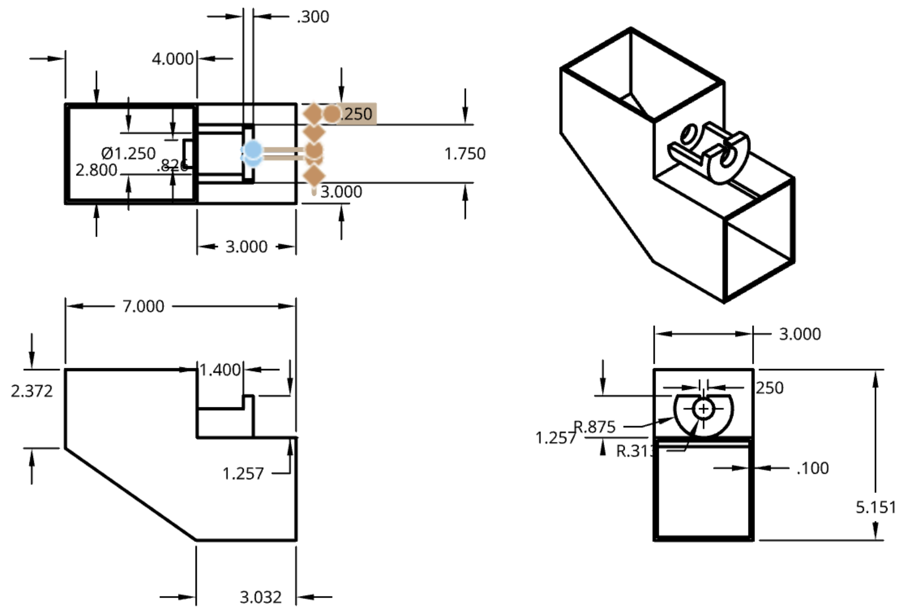

Figure 13: Main body housing[8]

Overall Design Rationale

The significance of this groove in the wheel is thus: it allows the car to remain firmly on the cable while traversing turns utilizing basic physics. As the car initiates a turn, its inertia resists this change in motion. Because the center of mass is well below the cable, this results in the bottom of the car swinging outwards away from the turn. When looked at relative to the wheel, this shifts the turn from solely in y direction to partially in the z direction, which the wheel is more equipped to handle. This is the same principle as banked turns on a race car track. This, coupled with the gravitational auto alignment that happens as a natural consequence of the cable sitting in the grove allows the car to stay on the cable.

The motor that drives this wheel was selected due to its relatively decent torque, low weight, and high rpm. (Figure 14) For this design, it was also important that the vehicle be able to get on and off of the cable with ease, as well as traverse clamps that enable the cable to be mounted.

8 Measurements for dimensioned figures 2-5, 7-11 are in inches.

Figure 14: Isometric picture of motor used

Within the suspension system, the springs provide a downforce that forces the wheel into the cable, improving grip. However, they are also compressible, which allows the wheel to be removed from the cable, as well as traverse the clamps.

Drivable Zipline Vehicle - Electrical Components

Description

The vehicle consists of mechanical and electrical components. The electronic system consists of several key components that work together to power and control the vehicle.

- ESP32-CAM Microcontroller (Figure 15): This serves as the central control unit, providing both video feed and motor control. It connects to the motor controller and operates with a maximum 5 volt power limit.

Figure 15: Picture of ESP32-CAM Microcontroller on the bottom

- 7.2 volt Battery (Figure 16): A rechargeable power source that supplies energy to the motor controller and ESP32.

Figure 16: Rechargeable battery with charger

- Motor Controller (Figure 17): This module regulates the delivery of power to the motor, allowing precise control of speed and direction. It receives power from the battery and signals from the ESP32.

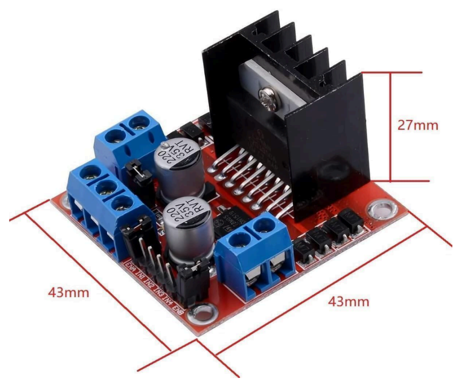

Figure 17: Motor Controller

- 7 volt motor (Figure 18): The motor is the driving force behind the vehicle.

Figure 18: Motor

- Buck Convertor (Figure 19): A voltage regulation device that steps down the 7.2 volt battery output to 5 volts, making sure that the ESP32 has a safe and stable power supply.

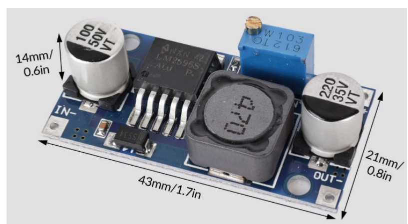

Figure 19: Buck Converter

Overall Design Rationale

We chose to use each one of these parts for specific reasons. (Figure 20) A special 7.2 volt that is normally used for control RC toys provides more amperage than normal alkaline batteries would which is needed to drive both the motor controller, motor, and ESP32. We chose to use a 7 volt motor to provide enough torque as the entire contraption is driven on ¼ tubing with a 4.4 diameter wheel. As such, we would need a battery with enough voltage to power that. However, the esp32 is only able to handle a maximum of 5 volts without overheating. The buck convertor comes in to step down the voltage from 7.2 to 5 volts. They are also laid out in the housing specifically so they have plenty of room without allocating too much space to where they may swing about. (Figure 21)

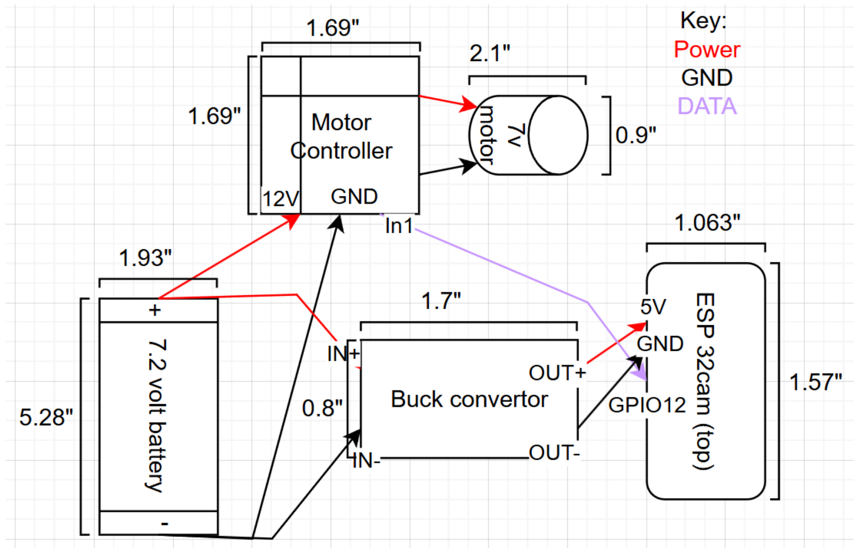

Figure 20: Layout of electronic wiring and components

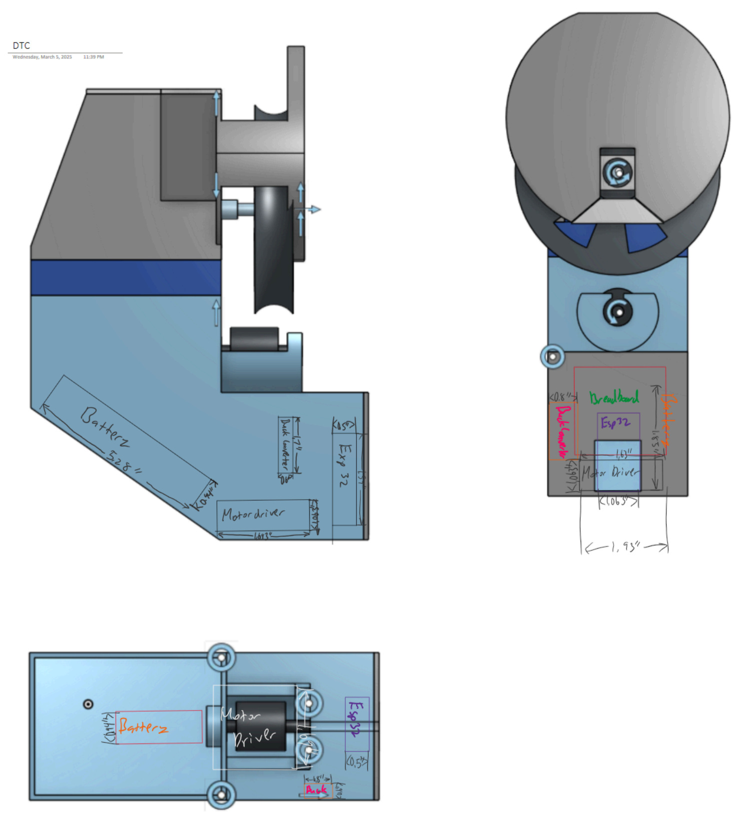

Figure 21: Placement of electronics in housing.

Web App

Description

The web app interface is built to be accessed using a smartphone or tablet from either the patient end or staff end. It will offer a real-time video feed (Figure 22) from the camera in the vehicle, displaying a clear view of the zoo exhibits for the patient to observe. The patient and staff will be able to communicate through an integrated microphone and speaker system in the web app, enabling two way audio. A control panel will allow the patient to maneuver the vehicle using on-screen directional buttons. The staff can also highlight specific areas within the video stream using a laser pointer tool, which overlays a visual indicator on the livestream.

Overall Design Rationale

The staff previously reported difficulty hearing the patient due to speaker issues in the telepresence robot. To address this, this system uses the microphone and speaker built into smartphones and smart tablets which are usually clear enough for the needed context. Enhancing engagement and making the tour more interactive were key priorities for the staff, and the ability to point out specific objects within the livestream helps achieve this by allowing them to guide the patient's attention more effectively. The control panel with buttons makes sure that the patient has an intuitive way to move the vehicle, fostering engagement and autonomy.

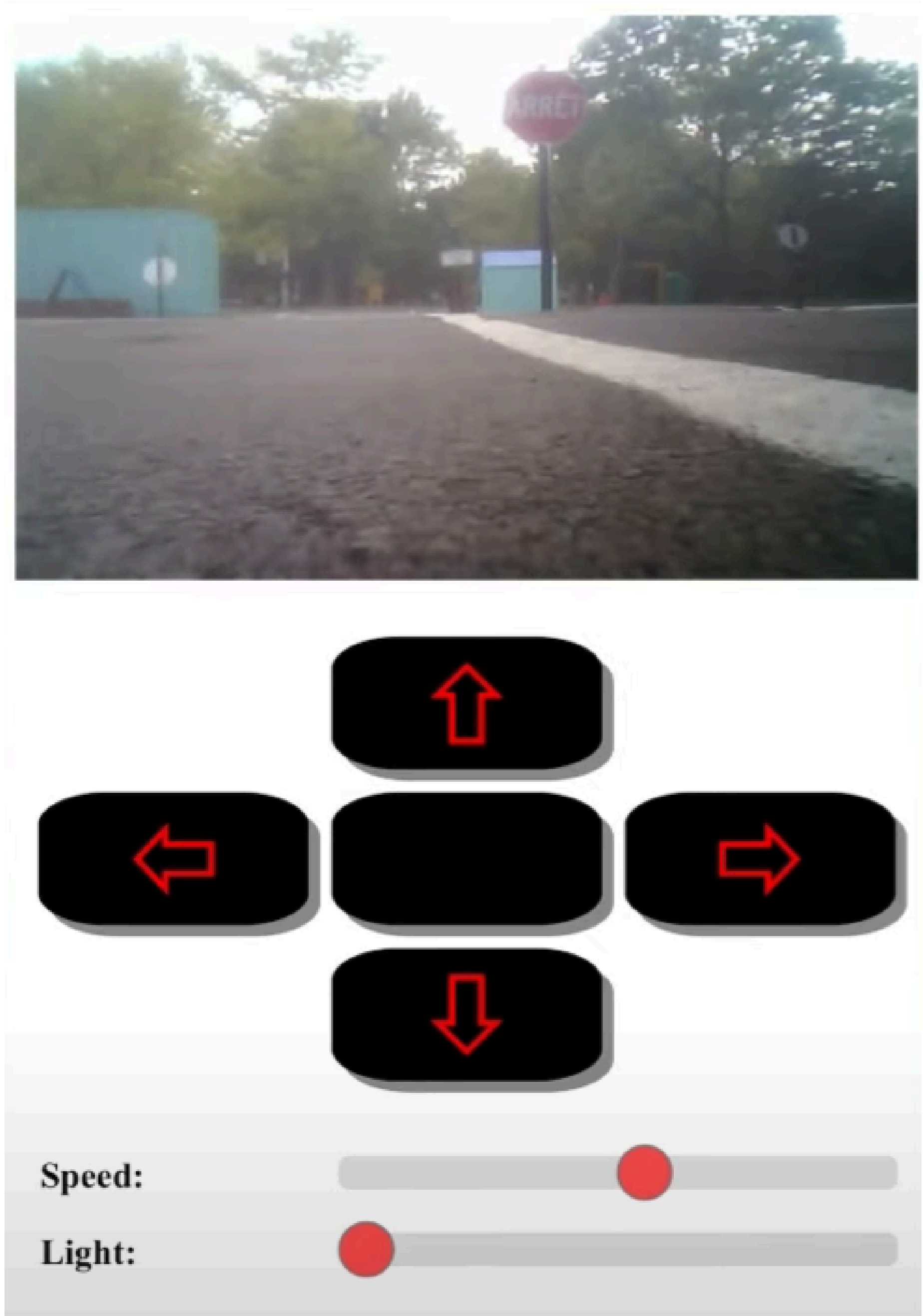

Figure 22: Web app display example of the livestream[9]

[9] Vehicle control buttons, microphone, and audio are not displayed.

Future Development

Given more time and resources, various routes can be taken to develop the Skynet System to make the telepresence tour more interactive and engaging for Lincoln Park Zoo's patients.

Wall Mount

A wall mount with an adjustable length would allow for an adjustable field of view and overall better viewing experience for the users. This feature would also allow educators and volunteers to determine the distance between the camera and the wall. Additionally, this adjustable feature would allow Skynet to navigate around obstacles more easily. A potential method to make the length of the mount retractable is to implement a spring button system with multiple holes along the wall mount.

Another feature that would improve the viewing experience is introducing hinges that allow Skynet to swivel horizontally and/or vertically and remain fixed in an angled state. This would further help Skynet navigate around obstacles.

Finally, in future iterations of Skynet, the wall mount would be designed with a sleeve to be fixed onto a track. These tracks would then be designed to attach to various surfaces, expanding Skynet's possible use to other indoor and outdoor exhibits. In theory, a putty track would be used for mounting on textured surfaces, a suction cup track would be used for mounting on smooth surfaces, and a cinched track would be used for mounting on outdoor objects.

Drivable Zipline Vehicle - Camera

Another aspect of the design that could be developed to improve the users' experience is the camera. Currently, Skynet would have trouble viewing smaller exhibits stacked on top of each other such as the Small Mammals and Reptiles exhibit. The camera height of a developed iteration of Skynet would be adjustable, allowing the device to view multiple exhibits at a fixed position. This feature would also increase the interactive aspect of the telepresence tour as it gives users more autonomy over their viewing experience. Additionally, in future iterations, the camera would be able to tilt horizontally and vertically, adding another degree of freedom for users.

Conclusion

To conclude, Skynet meets the expectations and demands of users of Lurie Children's Hospital and the operational requirements of the Lincoln Park Zoo staff. Our design is comprised of three major components:

- An interactive zip-line camera system controlled by a vehicle, providing a zoo exhibit view that keeps users engaged at all times.
- Cable and wall mount mounts that anchor the system to the zoo. In addition, the wall mounts enable low grad flexibility of the cable, thus improving the hold on the camera vehicle but making the cable rigid enough for reliable use.
- An easy-to-use web application that enables patients to control the camera and talk to the zoo staff, providing an interactive and educative virtual tour.

Skynet is easy to operate, lightweight, and impact-resistant which fulfills the requirements of the project. In addressing the limitations of previous telepresence equipment, such as heavy equipment and limited interactivity, Skynet creates a delightful experience for users at Lurie Children's Hospital.

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Appendix A: Secondary Research Summary

In order to gain insight into our end users—patients at Lurie Children's Hospital—and the operational difficulties of our project partner, Emma Martel, director of Child, Teen, and Family Engagement at Lincoln Park Zoo, we performed background research [4]. One component of the project was to create a telepresence system that would enable users to enjoy a zoo tour from the comfort of their own homes. The telepresence system would make the educational experience accessible even when patients are unable to physically visit the zoo. Our secondary research focused on understanding the crucial role telepresence technologies play for its users, the functional background of telepresence, and the geography of the Lincoln Park Zoo and how it fosters an interactive system. This research provided us with valuable insights into how to design a solution that is both user-friendly for patients and practical for zoo staff to operate.

Telepresence Necessity

The key users of such a telepresence device would be patients of the Lurie Children's Hospital, many of whom experience deep-rooted physical and emotional challenges related to their medical conditions and treatments. A child's normal life, which includes family, school, and social interactions, gets disrupted by hospitalization. This disruption results in loneliness, anxiety, and stress, which are not helpful in recovery and well-being. Studies show that non-clinical and interactive activities, such as virtual entertainment, greatly improve the normal psychological functioning of school-aged children by providing something to distract and entertain them [8]. Therefore, a telepresence-based solution seeks to solve these problems by providing children with the ability to view the Lincoln Park Zoo from their hospital beds [3].

Telepresence Applied

To align with the project's goals, the solution requires a device that enables users to independently explore the Lincoln Park Zoo. While researching potential approaches, existing telepresence technologies and their applications were examined to identify best practices and key requirements for the design. Telepresence systems have been widely adopted in various industries, including healthcare, education, and remote work, demonstrating their potential to bridge physical distances and create immersive experiences [6].

Telepresence systems enable the user to interact with a remote environment using a device that receives audio, video, and control input [13]. These systems often depend on teleoperation, which is the use of a human operator to control a machine remotely with real-time feedback. The operator typically uses a programmatic interface, which permits control over the device using system tools like joysticks, touchscreens, or vocal instructions. For instance, teleoperated robots are commonly used in industrial environments to work in dangerous places, keeping the operator out of harm's way while allowing close control of the processes [5]. Telepresence robots are also used in medicine where doctors are able to consult patients without being physically present which illustrates the flexibility of this system [11].

Recognizing how telepresence is used in sectors such as healthcare, education, and construction provided useful aspects like video capturing, two-way communication, and simple operation [12]. This information is helpful when it comes to creating a device that caters to both the zoo staff and user's needs. Additionally, the incorporation of friendly user interfaces and light but durable parts is consistent with the general tendencies of telepresence technology, which aims towards more accessibility and reliability over long periods of time [7].

Lincoln Park Zoo Topography

Spanning 35 acres, the Lincoln Park Zoo is home to a wide range of exhibits and programs and has a very extensive terrain [9]. Many of the pathways vary in design, with the Nature Boardwalk being the longest at a staggering 2,640 feet [10]. While the buildings are designed with the goal of promoting accessibility—featuring automatic doors and ramps—the areas that are outside have obstacles such as overhanging tree branches, a rugged ground, and tight walkways in some areas [2]. These factors could complicate the movement of a telepresence device, necessitating a design that accounts for these challenges to ensure reliable performance and an engaging user experience.

The success of the project hinges on a thorough understanding of the Lincoln Park Zoo's environment, as its layout and physical features present unique challenges for navigation. The zoo's diverse terrain and varied building structures must be carefully considered to ensure the device operates effectively and provides a seamless experience for users.

Figure 23: Lincoln Park Zoo's accessibility map.

The Lincoln Park Zoo has made significant efforts to provide inclusive programming, ensuring that individuals of all abilities can connect with nature. One such initiative was the use of a telepresence robot named Keo, which allowed guests with health concerns or limited mobility to virtually tour the zoo [1]. However, this solution faced challenges when the robot's motorboard failed, rendering it inoperable and highlighting the need for a more reliable and sustainable system. This setback highlights how important it is to develop a new telepresence solution that is not only durable and easy to maintain but also capable of delivering an engaging and accessible experience for users. By addressing these issues, the zoo can continue its mission of inclusivity and ensure that all visitors, regardless of physical limitations, can enjoy the wonders of the zoo.

Citations

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Appendix B: Interview Summary

Introduction:

The telepresence program at the Lincoln Park Zoo began with the purchase of an approximately fifteen thousand dollar robot by an anonymous donor in 2017. This allowed the zoo to begin telepresence tours for various clients. However, due to unfortunate circumstances, this robot stopped functioning, leading the program overseer Emma Martell to explore alternatives to continue the program. This led her to contact Northwestern's DTC department and partner with us to find a solution.

Methodology:

To gain a better understanding of the problem and desired solution, an interview was conducted with Emma Martell, the Director of Child, Teen, and Family engagement at the Lincoln Park Zoo, and Bill Green, a staff member who is heavily involved within the telepresence program. Given a lack of substantial information, questions were broad and aimed to acquire a general, unbiased understanding of the problem. The interview was conducted over Zoom on January 16th, 2025 at 10:00 am Central Time. The Zoom meeting was recorded for future reference.

Results:

Information given by Emma Martell and Bill Green throughout interview:

- The telepresence tour was beneficial for numerous reasons. Primarily, getting to the zoo itself can be a challenge for a couple of reasons. The scale of Chicago for one makes it difficult, however, there are also accessibility issues for certain people when it comes to navigating public transportation. This made the telepresence robot an ideal solution.
- The telepresence tours were popular because it was a way for the patients to have agency and be able to escape the hospital and exercise a certain level of mobility. It also allowed them to partake in a "normal" childhood experience, which helped combat feelings of being left out
- Zoom tours are less ideal, as they limit the autonomy of the patient
- The experience was somewhat video-game-like, as the patients controlled the robot via arrow keys.
- The user drove the robot around an exhibit, and a tour guide spoke to them, pointed things out, and explained them.
- The robot itself is about four to five feet tall and has a large screen on the front which displays the face of the child driving it. It is remote control operated and connects via wifi. It has a large

heavy base that houses the battery, which lasts for up to eight hours. The robot is simple to use, as it basically requires the user to simply push an on button. However, it is difficult to transport as it is very heavy. This means that users must put it on a cart and bungee tie it in order to move it. Additionally, it has very low clearance. The max speed of the robot is about walking pace.

- They had issues with young toddlers turning the robot off mid-tour thanks to the power button being a little too accessible. They also had issues with the sound, as often the tour guides weren't able to hear the user. The other significant issue was the weight. It was not particularly easy to move, which was not optimal. The robot was also fairly limited in where it could drive, and for that reason was primarily used indoors. One of the other significant issues that they faced was the fact that the parent company of the robot had been sold multiple times, making it super difficult to get any information about the fixability of the robot or any support through the process.
- They had an interest in connecting the robot to headphones with Bluetooth, but never successfully executed that.
- The robot is no longer operational due to a mouse corroding part of the circuit board
- The program generally provided a good experience for the patients, and there was even one who asked to stay longer in the hospital so they could drive the robot again.
- Tours were given primarily in the off-season
- The robot was housed in an office and had two staff members dedicated to each tour
- They are not interested in buying a secondhand robot as most are no longer supported

Discussion

Throughout the interview, it became evident that the most important element to our partner is the autonomous experience that the user had. This autonomy was meant to make up for that which they lost on account of being in the hospital. While they are open to non-robotic options, for that reason they believe a robot may be the best approach. If we were to replace the robot, it would require a couple of features. First, it would need to be able to traverse wet ground as well as smooth surfaces and some gradual inclines. The robot would also need at least a two-hour run time. In order to fully capture each exhibit, it would require a height of four to five feet and ideally have a camera that is able to pivot and zoom in. Due to the nature of the tour, having a high-quality camera is vital. The robot would need to be remotely operated through wifi and have an easy-to-use interface. Having a screen that can show the face of the child is not necessary. Having high sound quality would be ideal, and finding a way to integrate the sound with Bluetooth would also be a good solution. The robot doesn't need to be fast or able to traverse gravel or outside terrain, but making it stable and having obstacle avoidance would be helpful features. Finally, the robot should also have good longevity and be reparable should any component break. This means making it completely mouse-proof, and not using fragile custom parts. All in, the scale of the robot approach would require a substantial amount of engineering, although no single component is necessarily out of the realm of this group's capabilities. It is worth exploring further options and potentially incorporating some of the listed characteristics into an alternative design.

Appendix C: Observation Summary

Introduction

Patients at Lurie Children's Hospital face disruptions to their normal routines such as having to stay in the hospital for weeks on end. This can lead to increased negative emotions such as feeling "nervous, scared, annoyed, 'freaked out', and upset"[1]. Recognizing this challenge, the staff at Lincoln Park Zoo introduced a telepresence robot in 2017[10] to help mitigate these feelings. This allowed patients to experience the zoo remotely despite being unable to visit in person. While the initiative was well-intentioned, the solution had notable drawbacks. The robot faced significant physical and interactive limitations, reducing its effectiveness. Our goal is to develop an alternative telepresence tour that overcomes these challenges, eliminating physical constraints and focusing on enhancing interactive engagement.

To gather information for our project, we utilized multiple research methods, including an online interview, in-person observations, and follow-up communication.

Methods

As part of our research, two team members visited the Lincoln Park Zoo on January 24 for approximately one hour. During this visit, they met Emma Martell in person, explored the exhibits, and gained firsthand experience of the environment we aim to replicate virtually. They also observed the robot previously used for telepresence tours, noting its limitations and why it was deemed unfixable.

Our team members walked the path the robot would have taken children on, taking notes to allow us to better understand the flow and structure of the tour. Emma Martell provided answers to any lingering questions during this visit, which helped us refine our understanding of the project scope.

We, as an entire team, returned to the Lincoln Park Zoo on Saturday, February 15, 2025 to take some more notes and measurements. At this time, we had developed our prototype idea and were looking to do research more on how our prototype may be used rather than details about the zoo.

[10] As stated by Emma Martell

Results

The telepresence robot used for tours faced numerous limitations and challenges. Emma Martell told us that the screen often distracted the chimps. They also usually prefer to do their own thing and wander around, both of which make them less engaging for the tours.(Figure 24) The robot itself was slow and bulky, struggling to navigate obstacles such as uneven surfaces, internal doors, and long treks to outdoor areas. In these cases, the robot was strapped to a cart for transportation (Figure 25) due to its inability to traverse rough terrain. (Figure 26) Navigation also faced challenges like glare on exhibit glass, inadequate lighting, and dirty surfaces that affected visibility. The robot's two cameras—ground-facing and front-facing—helped prevent collisions and supported navigation, but their fixed positions made it difficult to adjust for exhibits with glass extending below the screen. The robot performed best on smooth surfaces like carpet or tile, as aggregate or pebble flooring caused further complications. While staff valiantly tried to improve control including experimenting with a game controller, tactile controls ultimately proved more effective.

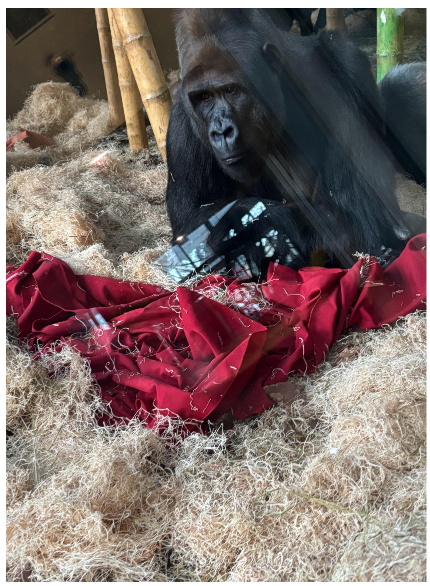

Figure 24: A gorilla sits behind a window pane seemingly disengaged. Note: Glare on window even using a high quality iPhone camera.

Figure 25: A staff member, likely Emma, demonstrates how the robot is transported between exhibits. Note: Very inconvenient!

Figure 26: This picture shows ground clearance issues more clearly. We can see that the wheels are not that big and the protective sides extend far down.

During the testing phase, team members had the opportunity to examine the robot closely and observed that its electronic board was corroded beyond repair.[11] (Figure 27)

[11] During the Zoom interview, we had already discussed that a replacement part was unavailable, which presented a significant obstacle to long-term use or further testing.

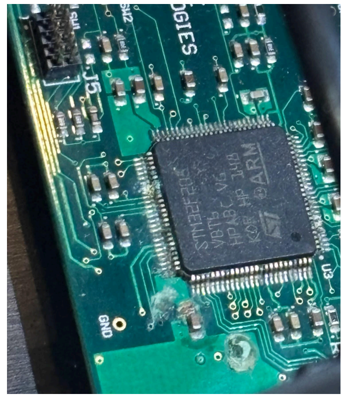

Figure 27: Electronic circuit board in the robot with stains and damaged solder. Note: Very complex.

Tours were designed to suit children's attention spans, focusing on one building and one species per session, with the building rotating monthly. Each exhibit was visited for 6–8 minutes, depending on animal activity, with primates, small mammals, reptiles, and the Regenstein African Journey animals being the primary focus. However, the tours often became repetitive, as only a single exhibit or small area was covered, and children typically lost interest after about an hour. Staff noted that if the robot worked successfully in one area, it was likely to function similarly in others.

Engagement and interaction were critical aspects of the tours. While the robot aimed to create an immersive experience, staff emphasized the importance of being able to see what the user (the patient) was viewing, rather than prioritizing the ability to see the user. Tours were led by educators and volunteers, with volunteers tasked with preparing exhibits, explaining the robot to visitors, and assisting with logistical issues like opening doors. Volunteers, who affectionately referred to the robot as "Keo," played an essential role in ensuring smooth operations. However, the robot could not move independently, and other visitors at the zoo could easily press its low-positioned shut-off button, leading to interruptions. Staff and volunteers underwent a two-hour training session, though more complex setups required additional practice to ensure confidence in using the robot effectively.

During our follow-up observation, we focused on examining the exhibit walls to determine how best to mount our prototype of the cable camera system. We visited almost every exhibit and took measurements to determine the necessary cable length for the system. This was important for ensuring that the camera would be able to traverse the entire exhibit and provide the patient with a comprehensive view.

In the Kovler Seal Pool, the available surfaces were primarily glass and concrete/brick. We noted that mounting on brick surfaces would be challenging due to its texture, while glass provided a smooth surface.

In other areas, we observed varying surface materials, including textured walls, smooth panels, and outdoor elements such as poles and railings. Additionally, in the Regenstein Small Mammal-Reptile House, multiple small enclosures were positioned closely together. (Figure 28)

Figure 28: Enclosures in the Regenstein Small Mammal-Reptile House.

We also noted that in many cases, the mounts would need to extend outward from the walls to prevent the camera vehicle from making direct contact with surfaces.

Discussion

The telepresence robot offered benefits such as engaging children for short periods and facilitating interactive virtual tours. However, its effectiveness was limited by physical design flaws, technical constraints, and maintenance challenges, highlighting opportunities for future improvements. The robot's slow speed, difficulty navigating uneven surfaces, reliance on specific flooring significantly reduced its mobility. On the other hand, environmental factors like glare, poor lighting reduced its adaptability. Its fixed camera lacked flexibility for zooming or vertical movement, limiting user engagement, while the bright power button was vulnerable to accidental shutdowns. Technically, the robot was outdated (having been in use since 2017), with corroded internal components and unavailable replacement parts making it unviable for long-term use. Additionally, tours focusing on one exhibit or species often failed to sustain children's interest, as unpredictable animal activity and limited variety led to disengagement despite monthly exhibit rotations.

Several practical constraints affected the tours. Operational hours were limited to regular business hours, and no tours were conducted during the summer due to higher zoo attendance, which left staff with less time to manage the robot. Additionally, prolonged periods of inactivity raised concerns about battery degradation. Other issues included glare from exhibit glass, robots being fixated on by gorillas due to uncovered screens, and dirty exhibits impacting visibility.

A more adaptable, engaging virtual tour solution is necessary. Removing physical constraints would enable features like dynamic camera angles, enhanced zoom, and better visibility, while incorporating gamification, live feedback, and broader content could improve interactivity and sustain interest. However, observations were limited to regular business hours and excluded peak seasons, while outdated technology restricted testing of advanced features. Addressing these gaps and incorporating lessons learned will support the development of a more robust, engaging virtual tour experience tailored to pediatric patients.

As part of our solution to these problems from the current telepresence robot, we noticed that mounting the cable camera system required careful consideration of exhibit materials and spatial constraints. Based on our observations, three main types of mounts would be most effective:

- Putty Track Mounts – Suitable for textured surfaces like brick (Figure 29) or rough concrete, as putty can mold to uneven surfaces and provide stability.

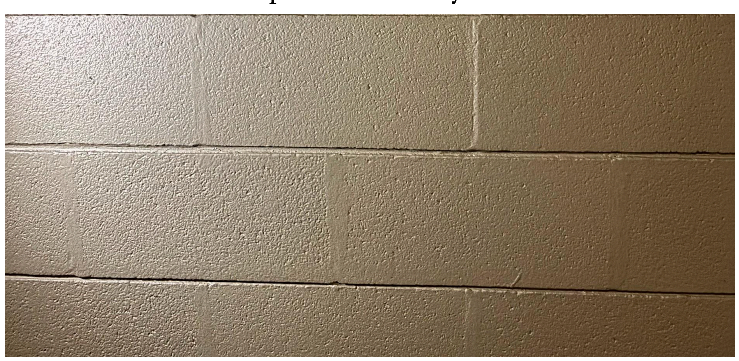

Figure 29: Brick wall where a sticky attachment would work best.

- Suction Cup Track Mounts – Best for smooth surfaces like glass, allowing for non-permanent adhesion without damage. (Figure 30)

Figure 30: Glass wall at the Kovler Seal Pool.

- Cinched Track Mounts – Ideal for outdoor objects like beams, poles, or railings, securing the cable track tightly for stability. (Figure 31)

Figure 31: Playground at the Pritzker Family Children's Zoo where cinches could be attached to the trees.

Additionally, in many cases, mounts would need to extend outward to prevent the camera vehicle from colliding with exhibit surfaces. This is particularly important in exhibits with limited clearance or irregularly shaped boundaries. Certain exhibits, such as the Regenstein Small Mammal-Reptile House, pose unique challenges due to their dispersed layout, making it difficult to establish a continuous cable track. Alternative solutions or additional mounting points may be necessary to navigate such spaces effectively. A more adaptable, modular mounting system is necessary to accommodate various exhibit constraints. Future iterations of the prototype should incorporate adjustable components to fit different surfaces, improve stability, and ensure seamless camera movement throughout the exhibits.

Overall, while the telepresence robot addressed some needs and provided valuable engagement opportunities, its limitations in navigation, usability, and environmental adaptability underscored the need for a more versatile, robust, and user-focused solution. This feedback provides a basis for future improvements to enhance the virtual tour experience and minimize these challenges.

Citations

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Appendix D: Mockup and Design Review Feedback

Mockup Feedback

Each team member created a different mockup version of the path that they wanted to explore and presented it for feedback to course professors.[12]

General:

- Mockups made it easy to visualize how the product would work
- Targeted end-user's specific problem
- Would have to observe both end-user groups using the mockup to determine whether this idea would work for them.
- Many bases covered

Strengths:

- The ideas prioritize stability and comfort, ensuring a better user experience, especially for children.
- Testing methods are practical, utilizing proxy users and real-world placements before committing to CAD models.
- Flexibility in design approach allows for adaptation, such as using off-the-shelf components or alternative mounting solutions.
- Process of choosing a design for mockup based on the viability of creating the product

Weaknesses:

- May not entirely solve problems. Reevaluate priorities: "must haves" vs. "nice to haves"
- Some key unknowns, such as mounting feasibility and adherence, need to be resolved before a final design.
- Certain ideas, like movement mechanics or battery limitations, may require additional research and iteration.
- The effectiveness of solutions may be difficult to gauge without real-world testing on the target user.

[12] Mockup was created and feedback was given before observing the end-user in person. Since receiving mockup feedback, one design was adapted based both on feedback given on the mockup and interaction with Emma Martell and Bill Green.

Design Review Feedback

During the question-and-answer segment, reviewers mainly asked clarifying questions to better understand the motive behind each design and the principles on which each of each functioned.

General:

- Reviewers had questions regarding what we as a team felt like we needed to be ironed out to have a final design.
- We should focus on what parts are unknown and what parts are crucial.

Phone Lanyard:

- Greatest concern is stability and we should test different placements of the phone
- Reviewers reminded us to be mindful of using CAD as a mockup as we should understand what we are testing by creating the model.

Virtual Tour:

- This is a very different idea than other suggested mockups.
- Reviewers said it would be a good way to test something Emma might have resistance to.

HEXBUG:

- Issues with distance and battery as products on the market do not have a long battery life.
- Reviewers had a question about how hexbugs move that will be in a possible next prototype.

Zipline:

- May not have 2 degrees of freedom, but there will be at least 1.
- Reviewers wanted to explore a more mobile version if mounting is the main issue.

Key Takeaways and Next Steps

After consolidating our ideas and deciding to move forward with the zipline idea, we presented a design review to the class.

Based on the questionnaire at the end, durability was identified as the least emphasized aspect of our design. However, given the constraints of this project, we are limited to 3D-printing components. While we can enhance durability to some extent, we must *acknowledge that our prototype will not be as robust as the final product could be.*

To improve manageability, we will *simplify the installation process for this project.* Instead of designing multiple mounting solutions, we will focus on one type of mount for a single surface to save time. For other surfaces, we will research existing solutions and compile these findings into the final report rather than designing them ourselves.

Concerns were raised about the vehicle obstructing zoo-goers' views. However, at just 1 ft tall and 5 in wide, the vehicle is relatively small. While we may be able to reduce its size slightly, *visitors should still be able to look around it to view the exhibit.*

Another concern involved servos potentially lacking the power to move the vehicle. To address this, we have *researched alternative motors with higher voltages and torque,* which should be capable of supporting the vehicle's weight and achieving the necessary speed.

Appendix E: User Testing Summary

Introduction

As part of our design development process, creating mockups is a crucial step in developing a solution. Mockups allow us to visualize concepts, test feasibility, and gather feedback to ensure that the final design meets the placed requirements. Our goal is to design a device that provides patients at Lurie Children's Hospital with an interactive, engaging, and informative telepresence experience at Lincoln Park Zoo. Up to this point, our team has conducted research on existing solutions, identified key requirements and constraints, and brainstormed several design concepts. Moving forward, each member has developed a mockup, with the goal of assessing the viability of each concept and narrowing down our solution. These mockups are designed to be flexible to change. This document summarizes the mockups we created, the testing we've conducted, and the feedback we have received.

Methodology

Our team developed our mockups on February 3, 2025, in the Prototyping and Fabrication Lab. On February 4, 2025, the team met with the DTC instructors in the conference room outside of room G211 to go over the mockups and gain feedback. On February 10, 2025, the team met with the project partners to gain feedback on viable options and hone in on a single mockup. After this meeting, the team decided to focus on developing Milo's zipline mockup. On February 13, 2025, the team went down to the Prototyping and Fabrication Lab to refine the zipline mockup and resolve possible design flaws. On February 15, 2025, the team as a whole went to Lincoln Park Zoo to determine the parameters we were working with and to further refine our zipline design.

Lanyard Mockup

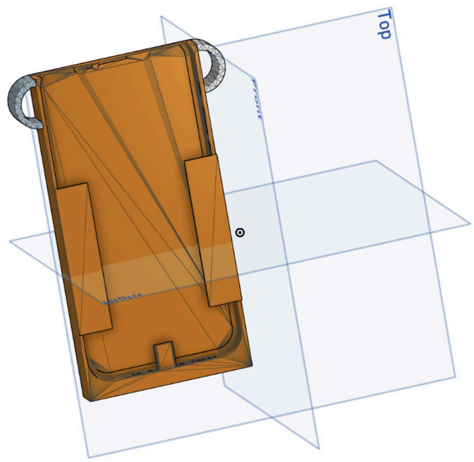

Figure 32: CAD design of lanyard mockup.

The lanyard mockup was a CAD file essentially portraying a phone case with handles on the upper corners of the case to which a strap would be attached (Figure 32). The user would place their phone in the lanyard and connect to the patient via Zoom, FaceTime, or other conferencing platforms. To understand how the lanyard would compare to the previous solution, we asked Emma about what height would be ideal for a telepresence tour.

Virtual Tour

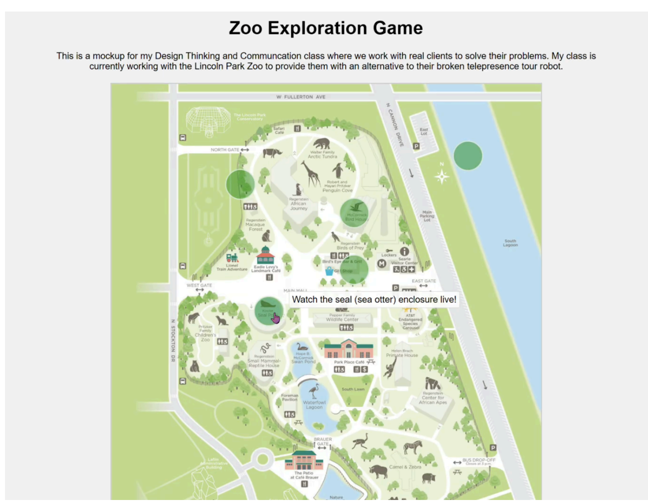

Figure 33: Webpage displaying an interactive zoo map.

The interactive game and vest mockup was a website that presented the Lincoln Park Zoo map with hyperlinks leading to live cameras (Figure 33). Additionally, when the cursor hovers over certain exhibits, fun facts about the animals in the exhibit pop up, providing the user with additional information. To increase interactivity, a colorful vest was made for the user to wear. In preparation for a meeting with Emma, it was important to ask what level of interactivity for the patients at Lurie Children's Hospital is necessary for a sufficient solution. Additionally, we wanted to know which exhibits had live cameras and if the live cameras were controllable such that they would be able to point at specific parts of the exhibit.

HEXBUG Mockup

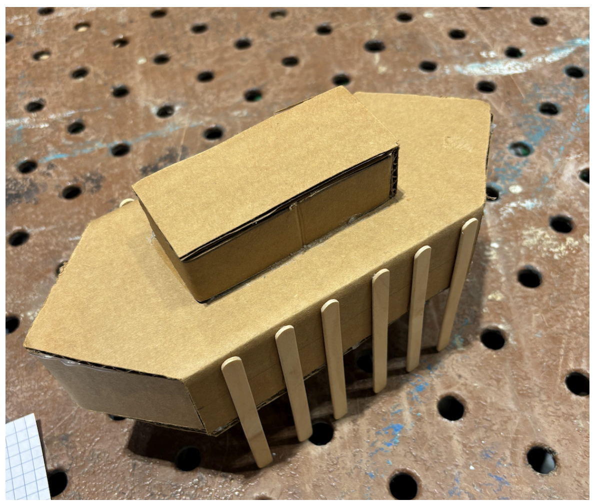

Figure 34: Cardboard HEXBUG model.

The HEXBUG mockup was a roughly 10in x 4in x 7in cardboard structure with a cardboard representation of a camera on the top and two holes on the bottom to represent inward fans (Figure 34). The popsicle sticks represented the legs that the HEXBUG mockup would use to traverse the exhibits. When making this mockup, we wanted to know whether installing pipes with which the HEXBUG could travel through was feasible. Our team also wanted to know what height the previous solution was to determine whether to design a HEXBUG that moves through transparent pipes or a HEXBUG that could climb on exhibit walls.

Zipline Mockup

The zipline mockup featured a string that represented the cable and a grooved wheel attached to a metal hinge. Below the hinge was a block of wood and a metal nut that represented the camera fixture. To test the zipline mockup, two people needed to hold two ends of the string at an angle, allowing the wheel structure to roll back and forth along the string. To develop an idea for the final design further, we decided to ask Emma if it would be feasible for the zipline mockup to be a permanent installment or a temporary installment.

Results

Lanyard Mockup Results

1. Testing: Because this mockup was a CAD representation of the prototype, no official testing could be done.
2. Emma's Questions
    a. How would you stabilize the lanyard on the wearer's chest?
    b. With what phone model would the lanyard be compatible?

Virtual Tour Results

1. Testing: No official testing was conducted with the interactive webpage. However, Ivan tested a vest to see if it fit.
2. Emma's Questions
    a. How interactive would this solution be for the patients?
    b. Could this be developed into an 8-bit game for patients to play?

HEXBUG Mockup Results

1. Testing: Because the HEXBUG mockup was a visual representation of the prototype without any function, the HEXBUG wasn't tested. However, the mockup aided in understanding the placement of certain features, namely the camera, in relation to the device.
2. Emma's Questions
    a. How long would the battery last?
    b. How would the HEXBUG climb on walls?
    c. Would the camera be placed at the bottom of the device or on the top?
    d. How fast would the HEXBUG traverse the exhibit?

Zipline Mockup Results

1. Testing: To test the zipline feature of the mockup, two people held up each end of the string and the wheel with the groove in it rode along the string.
2. Emma's questions:
    a. How tall would the zipline be?
    b. How would it be set up?

c. How interactive would this solution be to the users?

Discussion

Lanyard Mockup Discussions/Photos

1. The lanyard mockup was thought to be the most feasible and efficient solution. It didn't obstruct the general public from viewing the exhibits, and it provided the patients at Lurie Children's Hospital with a direct view of the exhibits. However, the main issue that Emma brought up was that the patients didn't have any autonomy over where the camera was positioned. Adding on to the limited autonomy over the device, the lanyard mockup as it was may lead to an unstable view of the exhibit because it is supported only by the wearer.

Virtual Tour Mockup Discussions/Photos

1. Emma and her associate liked the virtual tour mockup as a feature for a new informative app that Lincoln Park Zoo was developing. However, they determined that although the game and the vest provided patients with an interactive and engaging experience, the patients had little autonomy over what they could see or where they could move. Because of this, our team decided not to prioritize this route but rather to integrate aspects of this idea into our final design. This means allowing the educators to annotate what the patients can see.

HEXBUG Mockup Discussions/Photos

1. After testing the HEXBUG with the project partners, although Emma liked the idea, given the time and monetary constraints, designing a HEXBUG didn't seem feasible. Additionally, our team determined that we didn't have the expertise to design a small controllable HEXBUG with climbing capabilities, sufficient battery life, and sufficient mobility relative to the exhibit.

Zipline Mockup Discussions/Photos

1. When testing the zipline mockup with the project partners, we observed that increasing tension in the string makes the zipline more stable. However, we also observed that just putting a groove in a wheel and weight below for the mockup rendered the camera fixture and wheel unstable.
2. Additionally, we realized that using such a wheel design while turning a corner would also be unstable. At the Lincoln Park Zoo, we discovered that the suction cup works on glass and metal but not on brick, concrete, wood, or other textured surfaces.
    a. We also found that some mounts need to be angled and/or protrude outwards to view certain exhibits or bypass certain obstacles. At the small mammals and reptiles exhibit,

we found that to view the entirety of the exhibits, the zipline had to be closer to the exhibit than in other cases.

3. After testing these features, we determined that the wheel should have a concave groove so that the wheel remains on the cable even after turning a corner. Additionally, we decided to spring-load the wheel and bottom of the contraption to increase the amount of friction between the wheel and the cable, increasing the overall stability. We also decided that the mount should be a triangular wall bracket with a feature that makes it possible to adjust its length from the wall. On average, we determine that the cable should be 10 in from the exhibit, with exceptions such as the small mammals and reptile exhibit.

Appendix F: Bill of Materials

Bill of Materials						
Item	**Description**	**Qty**	**Source**	**Part #**	**Unit Cost**	**Total Cost**
Powered Wheel	3D Printed, 4 in Diameter	1	3D Printer	N/A	$0.00	$0.00
Non-Powered wheel	3D Printed, 1 in Diameter	1	3D Printer	N/A	$0.00	$0.00
Cable	100’ of Clear Vinyl Tubing	1	link	VT025-100	$11.99	$11.99
Springs	K = 19.6 N/in, max height 0.5-1”, min height 0.25”, diameter: 1”	5	Shop	N/A	$0.00	$0.00
Battery and charger	7.2V 3800mAh NIMH Battery (1 Pack) for RC Cars, 6-Cell NiMH Flat Rechargeable Battery Pack w/Standard Tamiya Connector + 7.2V Smart Charger(1 PCS)	1	link	XTRC0138NAD001	$22.89	$22.89
Buck Converter	5 Pack LM2596 DC to DC Buck Converter 3.0-40V to 1.5-35V Adjustable Voltage Regulator Electronic Voltage Stabilizer Power Supply Step Down Module	1	link	ASIN: B0DBVYP91F	$7.99	$7.99
Motor	Micro Motor DC 7V 6700-6900RPM High Speed Motor	1	link	ASIN: B07M8Q5J14	$9.29	$9.29

Motor driver	2 Pcs L298N Motor Driver Controller Board DC Dual H Bridge Module for Arduino Raspberry Pi Stepper Motor	1	link	ASIN: B0CR6BX5QL	$6.99	$6.99
ESP 32 cam	2PCS ESP32-CAM-MB, Aideepen ESP32-CAM W BT Board ESP32-CAM-MB Micro USB to Serial Port CH-340G with OV2640 2MP Camera Module Dual Mode	1	link	ASIN: B0948ZFTQZ	$19.99	$19.99
Mini breadboards with jumper wires	6Pcs SYB-170 Mini Breadboard + Multicolored Dupont Wire 10pin Male to Male, 10pin Male to Female	1	link	UPC: 618202524967	$5.99	$5.99
Double sided strips	Removable Double-Sided Foam Squares - 1/16" thick, 1 x 1"	1	link	S-13709	$18.00	$18.00
Bearings (we need 3)	Internal diameter 1/4 in 5/8 in external diameter .195 in thick	1	Link (10 pack)		$8.99	$8.99
Total Cost excluding tax						$137.11

Appendix G: Project definition

DTC 1 Section 13 Team 4

Project Name: Telepresence

Project Partner: Emma Martell from the Lincoln Park Zoo

Team members: Augustine Villalobos, Charmaine Guo, Ivan Dolphan, Milo Fernandez

Mission Statement

Design a telepresence experience that provides users in Lurie's Children Hospital with a fun, interactive, and educational experience and is also easy to operate by Lincoln Park Zoo staff.

Project Deliverables

- *Presentation and poster during the DTC Project Expo*
- *Final prototype*
- *Final report (digital copy)*

Design Constraints

- Must have positive impact on the users
- Must have reasonable learning curve for the volunteers
- Must show users dynamic animal activity
- Must be functional for a reasonable amount of years
- For this project, we have a budget of $150, but we should still look to minimize costs because the Lincoln Park Zoo is a nonprofit organization
- We have just 2 weeks to create our prototype for this class

Users and Stakeholders

- Users - Patients of Lurie Children's Hospital
- Emma Martell - Director of Child, Teen, and Family Engagement, spearheading the telepresence project
- Educators - use the device to lead tours and inform users about animals
- Volunteers - inform members of the public about the device, ensure that device remains unobstructed, and inform educators about engaging exhibits in advance
- Members of public - Entirely random people who will interact with the product during visits to the zoo

User(s) Profile

Patients in Lurie Children's Hospital may experience physical or emotional pain due to their treatments. While a visit to the zoo could provide comfort and distraction, medical restrictions prevent them from going in person.

Illustrative User Scenario

The user in this illustrative scenario below is based in part on an interview with Emma Martell. She spearheads the telepresence project that collaborates with patients at the Lurie's Children's Hospital. This project began with a fifteen thousand dollar robot by an anonymous donor in 2017 and has since been kept alive. Emma Martell described her experience working with the robot and the issues with her and her coworkers.

First, staff members retrieve the robot from an office. The robot itself is very heavy and must be on a cart to be transported longer distances to an indoor exhibit. It is then turned on by two staff members who will continue to monitor it as it travels around. They connect with the child at Lurie's Children's Hospital and make sure the sound, video, and controls of the robot are working properly. The staff at LPZ have had issues hearing the children and have thought about using headphones, but have not successfully tried it. After an hour or so, the child tends to lose interest due to the robot just being in the one exhibit for the entire time. One day, the team discovers that the robot is not able to turn on. The staff opened it up to find that there were mouse droppings that corroded the board. After consulting with the engineering department, they decided that the board had to be replaced. However, LPZ has had a lot of issues trying to contact anyone who could help because the parent company had been sold many times. As much as Emma wanted to fix the robot and continue providing a telepresence tour for the patients, this project had to be set on hold, until she could work with people that had the time and dedication to provide an alternative solution.

Project Requirements - Needs Identification, Metrics, and Specifications

Needs	Metrics	Units	Ideal Value	Allowable Value
Easily transported by one person	Weight 50	lb	5-10 Based on WiralCam zipline camera solution	60 Approximate Weight of current solution

	Max length 2	ft	~250	2 Based on charging station area of the current solution
	Max width 2	ft	At most 2 from mount surface	1 Based on charging station area
	Max height 6	ft	5'2 Based on previous robot specifications	5-6
Is easy to install	Simple design	Number of fixable components (from zoo perspective)	3	5 -Mount, Adjust angle, Clamp on cable, Attach camera fixture to cable, Connect user to camera and device
Engagement/Interactiveness	Amount of time they are engaged with the volunteer and tour	Hours	1-1.5 hours	1 hour
Must be able to traverse interior of exhibits	Max Speed safe throughout exhibit	mph	At least 2 mph	1.5-10

			Based on the previous robot's specifications	
Must be able to view exhibit	FOV and joints	Degrees and number of joints	At least 170 degrees Based on the previous robot's camera field of view Two or more joints to move side to side and up and down and possibly across	170 degrees Two joints to move side to side and up and down

Appendix H: Instructions for Construction, Installation, and Use

Introduction

The SkyNet system is a cable car-like vehicle that drives along the walls of a zoo exhibit. This vehicle will be remotely operated via a wifi connection, capable of live streaming video, low maintenance, easy to install and uninstall, and within the given budget.

The vehicle consists of a body housing the camera, battery, and onboard computer as well as a wheelhouse containing the suspension, motor, and upper and lower wheels. It clamps onto a cable mounted using proprietary mounting. Key features of this design include a cable clamp compatible with the flanged wheel and cable suspension, an adjustable frame with a sleeve for mounting, and a frame-to-surface adhesion track that slots into the aforementioned sleeve. Currently, Lincoln Park Zoo staff can use a command strip to attach the adhesion track onto a surface.

SkyNet System Construction

Constructing the SkyNet device requires:

- One or multiple 3D printers
- An X-acto knife
- Pliers

It will take approximately 24-48 hrs depending on the number of 3D printers available.

Parts list

Parts	**Specification**	**Quantity**
PLA Filament	Filament Diameter: 1.75 mm	1 Spools
Bearings	ID: ¼”, OD: ⅝”	3
ESP32-Cam	Microcontroller and board with camera	1

Buck Converter	L298N	1
7V Battery	Rechargeable batteries used for drones is best	1
Breadboard	Mini size: 35mm x 47mm	1
Motor Driver	LM2596	1
7.2V Motor	Diameter of 24mm, axle diameter of 2mm	1
Jumper wires	Male to Male	9
Tape	Double Sided	1 roll

Steps for construction

1. Here is the link to the wall mount, mount track, and SkyNet device STL files. https://github.com/willowcharm6/LPZ-DTC/tree/main[13]
2. Print a copy of all of the files with tree supports.
3. Cut and remove the supports from the SkyNet device

Figure 35: What supports should be removed

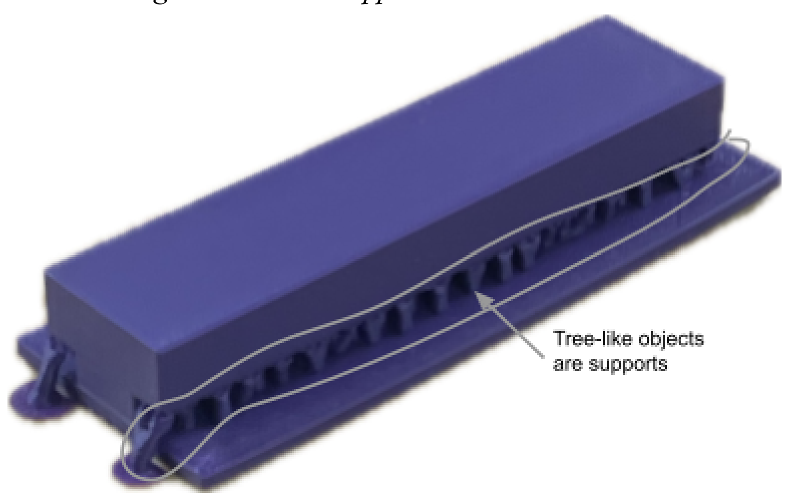

Figure 36: What supports should be removed

4. Assemble
   - Springs should be chosen using trial and error shooting for a downward force strong enough to maintain a firm group on the cable, but not so substantial that the wheels are no longer able to traverse the mounts.

[13] The code is included in the repository, but it is not necessary to download. Rather it is there if others want to iterate on it.

- To install the springs, hold the cage upside-down and place springs inside the spring compartments. The installation of the second spring in each compartment will require compressing the first spring

5. Follow this wiring diagram to connect the electronics (Figure 35).

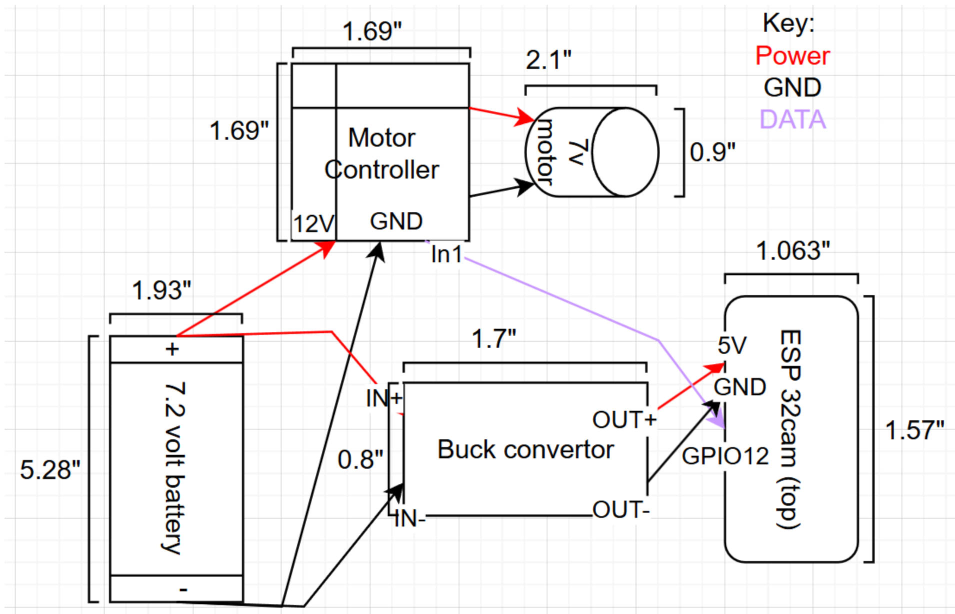

Figure 37 : Electronics wiring diagram

6. Unscrew the wires connecting the motor to the motor controller.
7. Place the motor in the motor cage rails, ensuring that the wires connecting it to the motor controller are on the side with the hole.
8. Bring the wires down the hole and screw the wires back into the motor controller.
9. Tape the battery down to the inside bottom of the vehicle with double sided tape.
10. Tape the buck convertor to either side of the inside bottom of the vehicle with double sided tape.
11. Place tape on the ESP32-cam, behind the camera, like so (Figure 36):

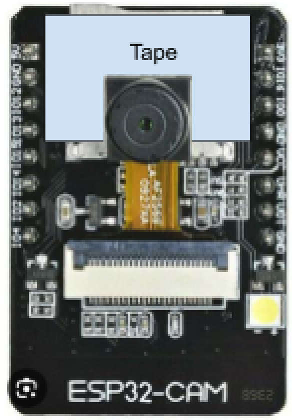

Figure 38 : Tape placed onto ESP32-cam

12. With the camera outside of the bottom part of the vehicle, press the tape down onto the plastic above the hole like this (Figure 37):

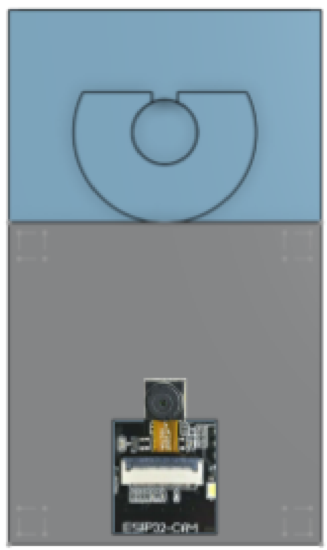

Figure 39 : Positioning of ESP32-cam in vehicle

13. Construction done!

SkyNet System Installation

Installing your SkyNet system is a simple process that requires minimal experience and takes no more than approximately 20 minutes (depending on scale of installation). The process requires one person, although more people accelerate the process significantly. The following instructions will detail the components required, the step-by-step instructions, and critical safety information to allow for a positive experience when setting up the system.

Parts list

Parts	Specification	Quantity
Cable	Outside diameter: .336”	100’
Command Strip	Size: Medium or Large	20
Wall Mount Tracks	See *Figure 38*	20
Wall Mounts	See *Figure 39*	20
SkyNet Device	See *Figure 40*	1

- Cable: Vinyl Tubing or any cable of a .336” outer diameter
- Command Strips: Any command strip of standard or larger size should work as intended
- Wall Mount Tracks: Come with wall mounts, should be attached to command strip to allow for wall mounting

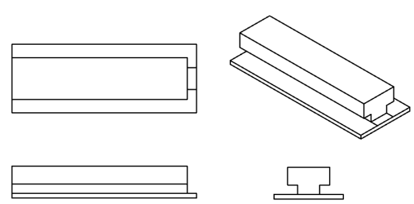

Figure 40 : Sketch of Wall Mount Track (front, top, right, isometric)

- Wall Mounts: Slide onto wall mount tracks, contain swiveling clip and adjustable stock

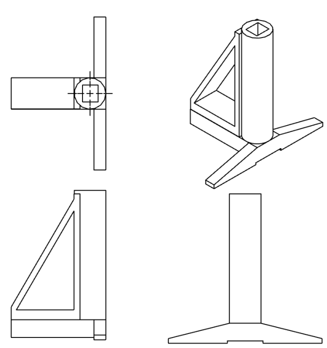

Figure 41 : Sketch of Wall Mount (front, top, right, isometric)

- SkyNet Device: Features suspensioned wheel, will clip into place on cable

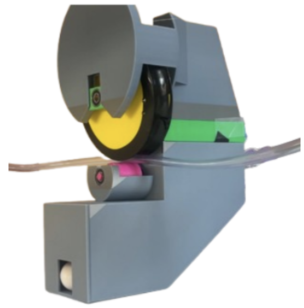

Figure 42 : Image of SkyNet device

CRITICAL SAFETY:

While compact and lacking significant inertia, the SkyNet device is capable of doing harm if used irresponsibly. MOST CRUCIALLY, ensure that each mount is secure before placing the device on the cable. Unsecured mounts could lead to the device falling and potentially injuring small children. Additionally, it is vital that both end mounts are used on either side of the desired path, as this prevents the device from flying off the track and maintains sufficient tension in the system.

Steps for installation:

1. Identify a region where setup is desired
2. Uncoil the cable and place it beside the desired wall/path, making sure not to damage it
3. Approximately every six feet, or as close to six feet as possible, place a command strip at the desired height on the surface and adhere the mount track to the strip
4. Secure the first end mount in place at the designated starting point on the cable and ensure it is firmly attached before proceeding.
5. Position and secure the interim mounts along the cable as needed for stability and proper spacing.
6. Attach the final end mount at the opposite end of the cable, ensuring all mounts are secure and aligned.
7. Pick up the cable and place it into the mount clamps. Slide the pin shut to secure the clamps

Figure 43 : Image of Mount Clamps holding Cable

8. Adjust clamps to the desired length
9. Place the SkyNet device on the cable
10. As the electronics are always on, the ESP32-cam should be ready to go.

SkyNet System Use

To use the SkyNet system, connect to the ESP32-cam Wifi called SkyNet with password: pleasework1. Navigate to this web server: 192.168.4.1 and you are good to go!