Receiving Station for Drone Deliveries

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Executive Summary

With researching and developing a drone delivery system, there are certain limitations and restrictions it must overcome. One of the biggest problems with a drone delivery system is maneuverability around a crowded residential area. Currently, drones need to land in an open area, but that can be problematic in less spacious areas. Most residences have obstacles such as trees, power lines, and light posts that can impede the drone's ability to land. Thus, our design solution for this problem is to build an 18 foot tall system that clears most obstacles, safely catching a package dropped by a hovering drone, without the drone landing, and to transporting the package to a more accessible area for the consumer to pick up.

Our design solution is to create a receiving platform run by a motor. The theoretical idea for our solution is to catch the package as it is free falling by accelerating the receiving platform downwards to closely match the velocity of the falling package. Because of the similar velocities, the package landing on the platform will impart a very minimal average force due to *impulse momentum theory*, thus, greatly reducing the chance of any damage on the package. The key features of our proposed designs include an ultrasonic sensor that will detect the package, a rack and pinion, a counterweight, the receiving platform with dampening foam, and a T-slotted frame that will vertically guide the movement of the counterweight and receiving platform.

To evaluate the success or failure of our design solution, we modeled a virtual design using SolidWorks as well as built and machined a physical prototype. In SolidWorks, we were able to fully simulate real-world conditions such as the weather, environment, and mechanical properties of materials. In our SolidWorks simulation, we designed a drone to deliver and drop a package, and our design solution was able to function as we intended to without any problems. For our physical prototype, we simplified many mechanisms to simply show a "proof of concept." We used an Arduino and a stepper motor to simulate the controls aspect of the design. Common problems that occurred include gear slippage, friction, lack of motor power, and delay in the sensor. Recommendations for improving this design can stem from better materials, better coding for the Arduino, a dedicated power supply, and the use of a photo sensor or laser instead of an ultrasonic sensor to remove the delay in detecting the package.

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1. Introduction

On December 1st, 2016, Jeff Bezos, CEO of Amazon reveals on CBS' *60 Minutes* the idea of using a fleet of drones to quickly deliver packages to consumers. Ever since Bezos' public announcement of developing a drone delivery service, other logistics services and companies decided to do the same. Companies and services such as United States Postal Service (USPS), FedEx, DHL, UPS, and even 7-Eleven are researching and developing their own drone deliveries to keep up with technology, and more specifically, Amazon. This new concept revolves around the idea of utilizing drone technology to transport packages to customers and stands as a primary inspiration for our project. Many challenges, however, are certain to rise from this method of delivery. Thus, these challenges stand as a motivation for our intended project. One of the challenges is the means of properly accepting the delivery upon the arrival. Thus, our problem statement is the means of making a device that can properly accept packages dropped in free fall from drones. The intended customers for this device are regular online delivery users who own residential property. This report will begin by presenting the devised design solution followed by an analysis demonstrating its plausibility, and providing the approach undertaken for the solution.

2. Problem Statement

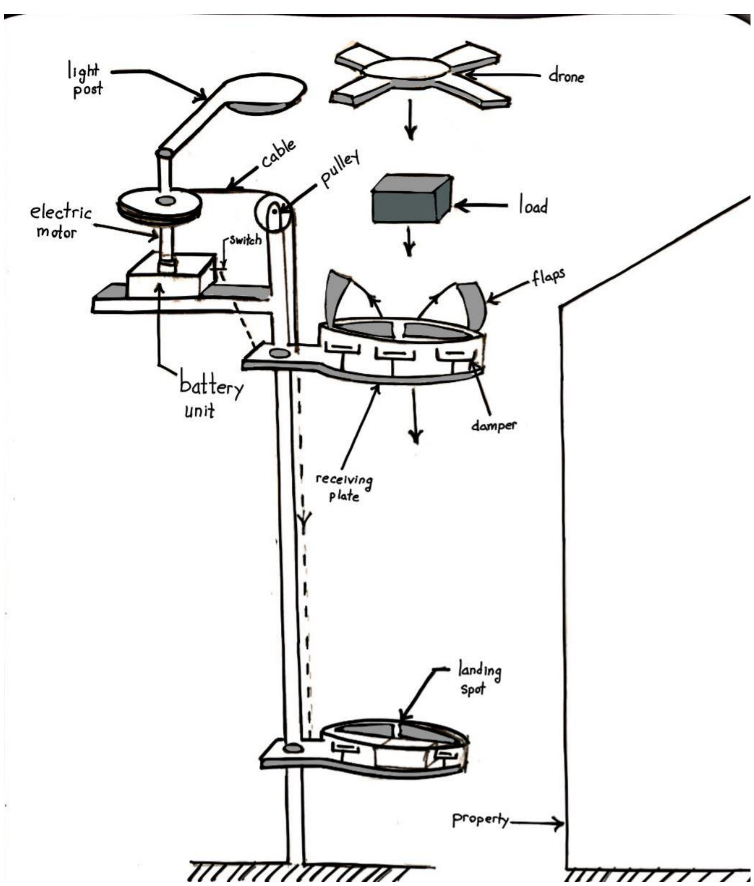
The drone based delivery system along with basic facts regarding homes in the United States has influenced our problem definition. The nature of the drone based delivery involves an active drone that would maneuver around a home to provide delivery. Most homes however, have trees, light posts, gutters, possible power lines and other obstacles that can potentially be hazardous to the drone itself as it will presumably have to maneuver around it. The lower the drone would have to go down to the landing spot, the more obstacles it will presumably encounter. Thus, to provide efficiency, it is best for the drone to remain at higher elevations relative to the property. Furthermore, environmental factors such as high winds can influence this system. Thus, our problem definition is to make a device that can receive the package dropped by a drone from a height of 18 feet from ground level, protect it from theft and environmental factors, and transport it to an intended location for the recipient under the conditions of a maximum wind speed of 5 mph and a drone horizontal velocity of within 2mph.

3. Design Solution

3.1 Conceptual Design to Detailed Design

The "Top Down Approach" was implemented to break down the main function of our design to several sub functions. The main functions of our designs consist of the ability to catch a falling load, absorb the impact, and transport it to a location for pick up. The sub functions for the design include opening of the flaps of the receiving plate, lifting and lowering of the receiving plate, rotation of pulleys, and providing a light post for aesthetics. The chosen conceptual design to accomplish these mechanisms is shown in Figure 1.

Figure #1 Conceptual Design of Motor Powered Receiving Tower



Applying further analysis to the conceptual design; we were able to generate a detailed design model using SolidWorks 2017. The detailed design model consists of two critical changes. The lifting mechanism for the final detailed design was replaced by a gear rack approach and the flaps were not considered. The key features for our chosen design are shown in Figure #2. The key features and functions are illustrated in Figure #3.

Figure # 2 Overview of Design

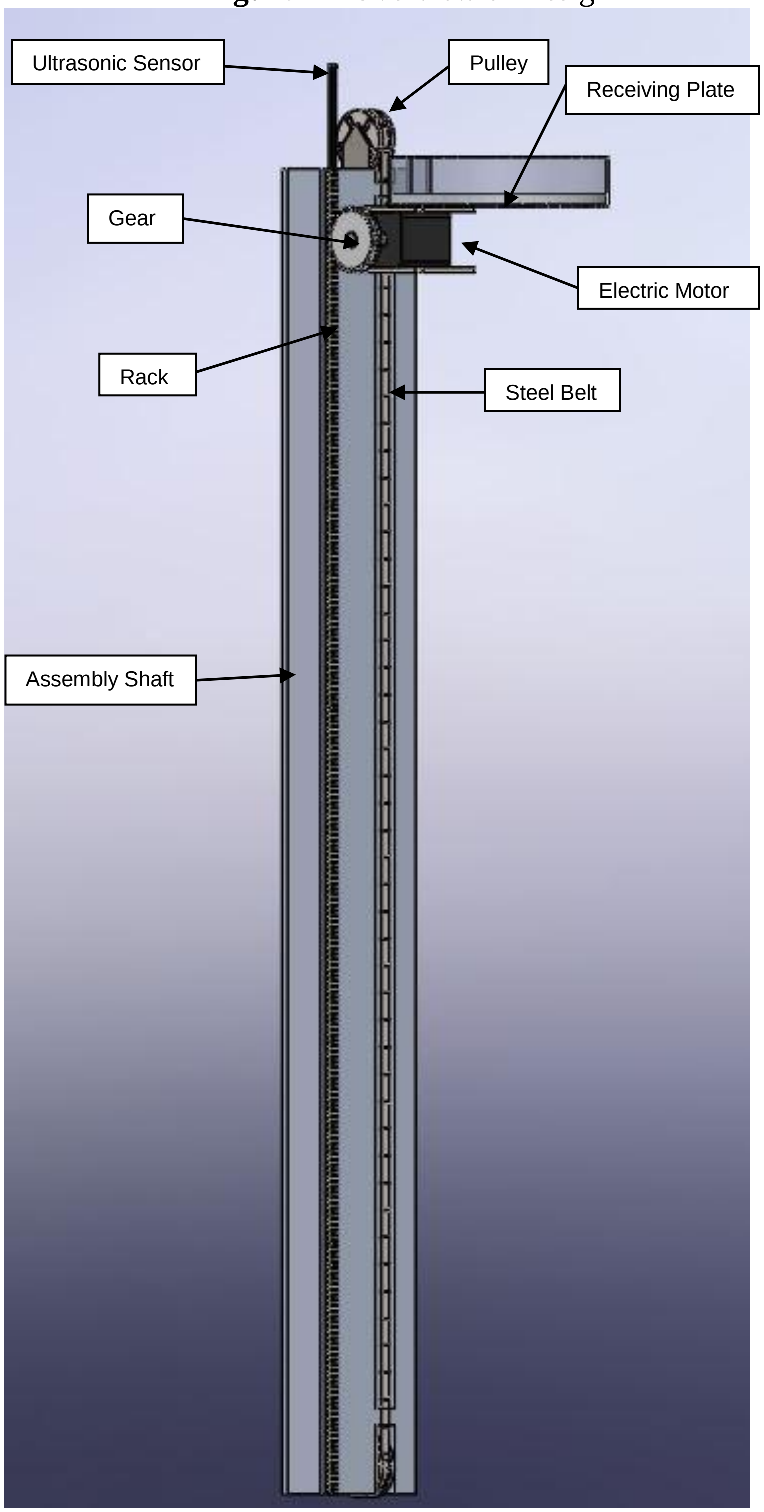
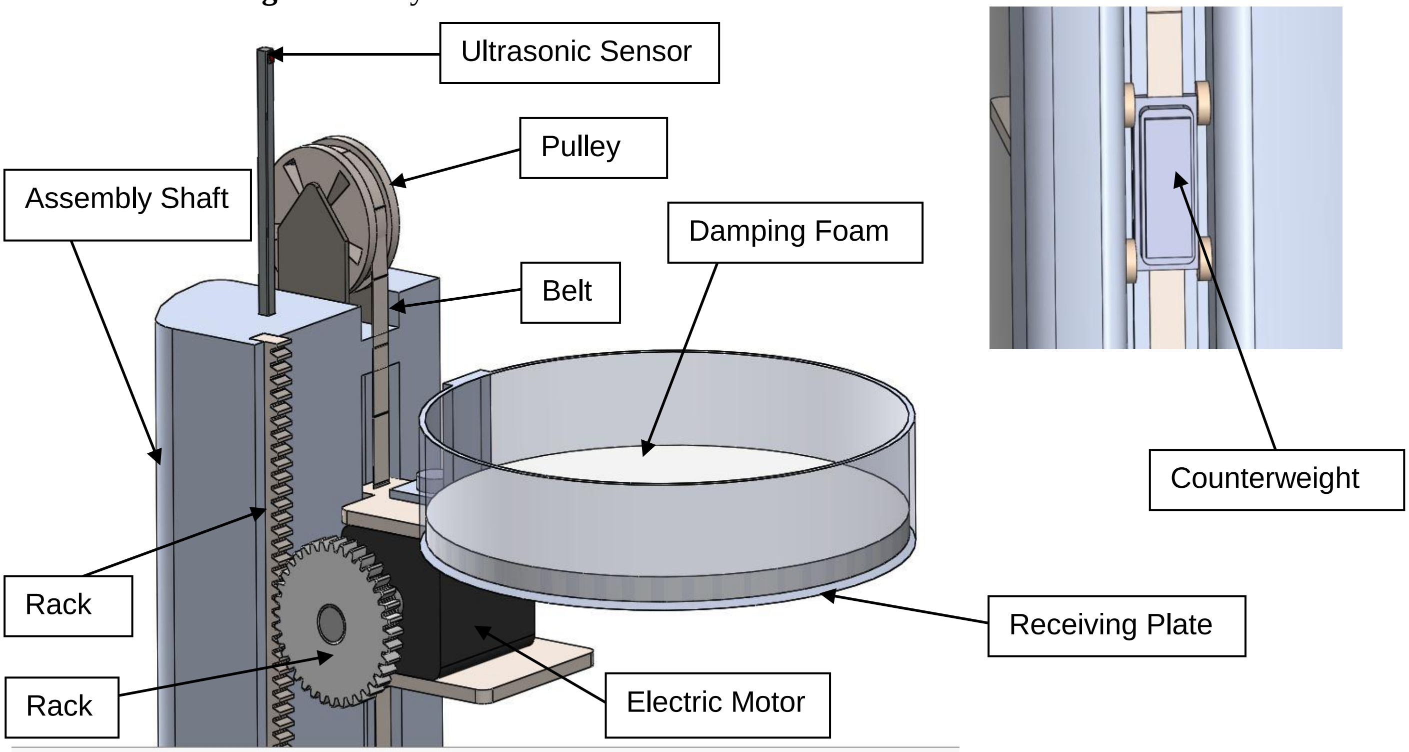


Figure #3 Key Features and Functions



3.2 Design Description

As mentioned before, drone deliveries require clearance space from obstacles. Therefore our chosen design resembles an 18 feet tower shaft. The primary function of our chosen design is to provide a lifting and lowering mechanism. The receiving plate rides along the main assembly shaft. This feature, as will be described stands crucial to receiving, protecting, and transporting a package dropped by a drone down to an intended location.

3.3 Functions of Key Features

Our chosen design consists of nine main features, each of which has specific function. The ten primary features include the gear, rack, electric motor, receiving plate, damping foam, continuous belt, an ultrasonic sensor, pulley and of course the main assembly shaft. The electric motor provides power to the gear which in turn rides along the rack. Thus, the torque provided by the electric motor allows, the main receiving plate to move up or down the main assembly shaft. A counterweight rides along the back of the main assembly shaft. The counterweight and the receiving plate are supported by a continuous belt along top and bottom pulleys. The purpose of the counterweight is to match the weight of the receiving plate and electric motor, thereby keeping the system in equilibrium. The receiving plate serves as the target location where the package is intended to land. It is circular with a diameter of 1 meter. The damping foam, shown in white, sits inside the receiving plate to soften the falling impact. An ultrasonic sensor sits on top of the main assembly. This provides key electrical inputs to the motor. A critical theme of our design involves catching the falling mass. This is accomplished with the ultrasonic sensor and the motor. As the mass passes by the ultrasonic sensor, the receiving plate shall accelerate downward to a location along the shaft that matches the speed of the falling mass upon contact. Once it is caught, the receiving plate steadily descends downward to deliver the package.

3.4 Overview of Design

The environment for which our design must be compatible with is outdoors near an average residential house as shown in Figure #3. The graphic illustrations help visualize how are chosen concept will actually blend with its appropriate environment. What a drone delivery will be expected to look like based off of our design upon the receiving and transporting end is shown in Figure #5 and Figure #6 respectively.

Figure #4 Overview Design with Environment

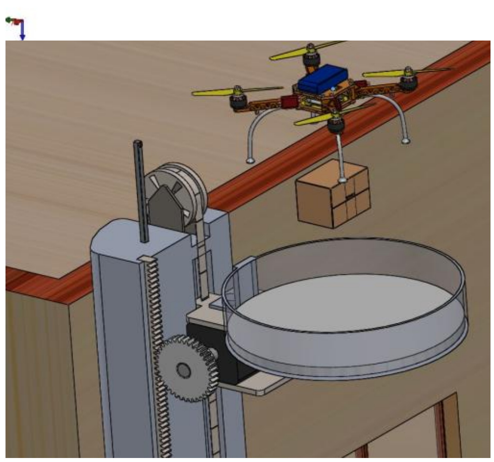


Figure #5 Drop Scene

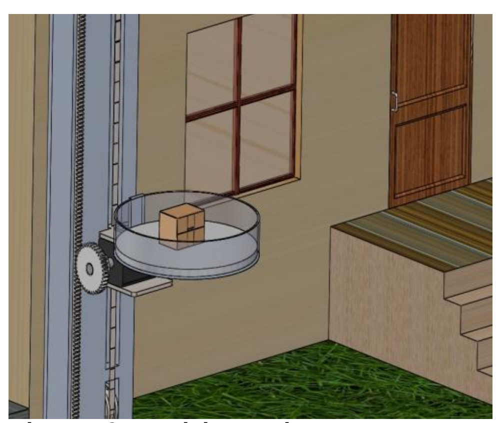


Figure #6 Receiving End

3.5 Constraints and Assumptions

Several constraints and assumptions are implemented in the design for functionality purposes. The materials used to construct the components of the device shall be assumed to live up to their physical properties. These include factors such as the yield and tensile strength. As the drone approaches the target location, it must be at a maximum height of 5 feet above the center of the receiving plate and have a maximum horizontal velocity of 2.2 mph. Wind conditions may vary, but the maximum allowable wind speed in any arbitrary direction will be no more than 5 mph. Air resistance within this range shall be designed to be negligible and not affect the functions of the design. The acceleration due to gravity will be presumed as $g = 32.2\frac{ft}{s^2}$. With regards to the load, the minimum weight is constrained to 1 lb with a maximum weight of 50 lbs. Furthermore, the package dimensions shall not exceed 1 x 1 ft.

3.6 Physical Prototype Design

A physical design was machined together to resemble our virtual design. The purpose of a physical prototype is to create a scaled down representation of the virtual model that can detect the velocity of a falling package and obtain it with a receiving plate. It is composed of an ultrasonic sensor that is used to detect the falling mass, and activate a motor to move the object along a rack . The weight of the receiving plate, stepper motor, and slider are held in place by a counter weight using a pulley system. This allows each of the components to remain stationary at the top of the assembly shaft when there is no operation taking place. The motor itself is attached to a gear and held in place by a slider that enables a smooth transition throughout the rack. The rack is attached to an aluminum strip to keep it immobilized and the receiving plate is pinned to the rod to remain static. We used a Bipolar motor (20x30mm) operating at 3.9V, since we need a small motor to fit with our rod and one that can operate with low power.

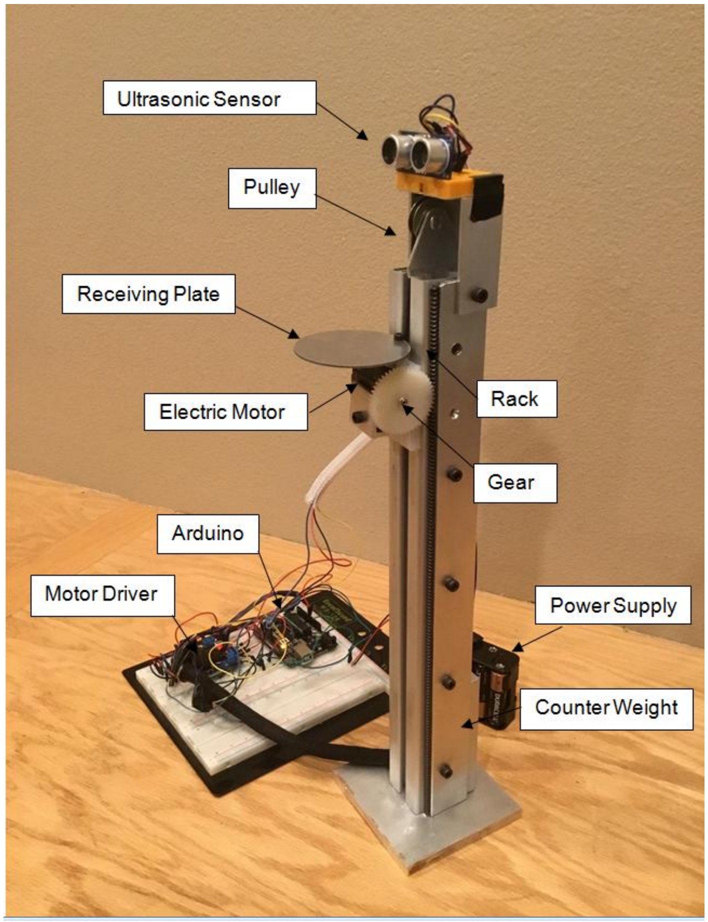


Figure #7A Physical Prototype-Side View

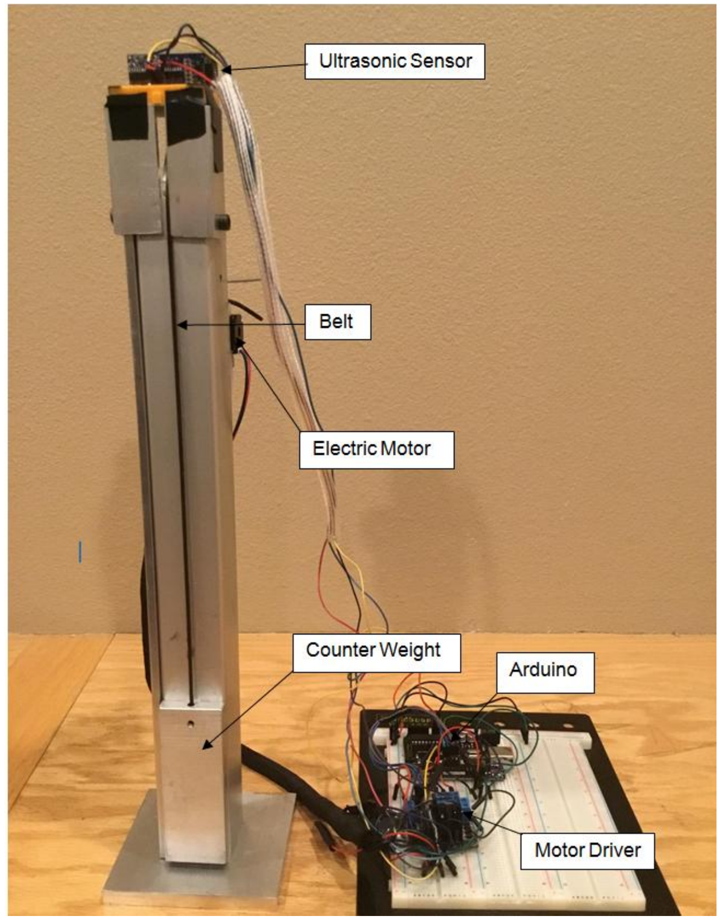


Figure #7B Physical Prototype- Back View

The electrical components used to operate our motor include an arduino board, motor driver, ultrasonic sensor, as well as a 9V battery. The code inputted in the arduino allows us to alter the functionality of the motor itself. We were able manipulate the speed, number of revolutions, direction, as well as the delay time of the motor that best fits the conditions for our design. The arduino board itself however, provides a low-current control signals to the motor, so a motor driver is obtained to fix that problem. The motor driver is a little current amplifier attached to the arduino board to provide higher- current signals that can drive the motor. The ultrasonic sensor is also attached to the arduino and is the key to starting up all the components. Once the object is detected by the sensor, the code for the arduino will be read, activating the driver and motor. A 9V battery is attached to the circuit board as well to provide efficient power to the arduino, ultrasonic sensor, motor driver, and the motor itself.

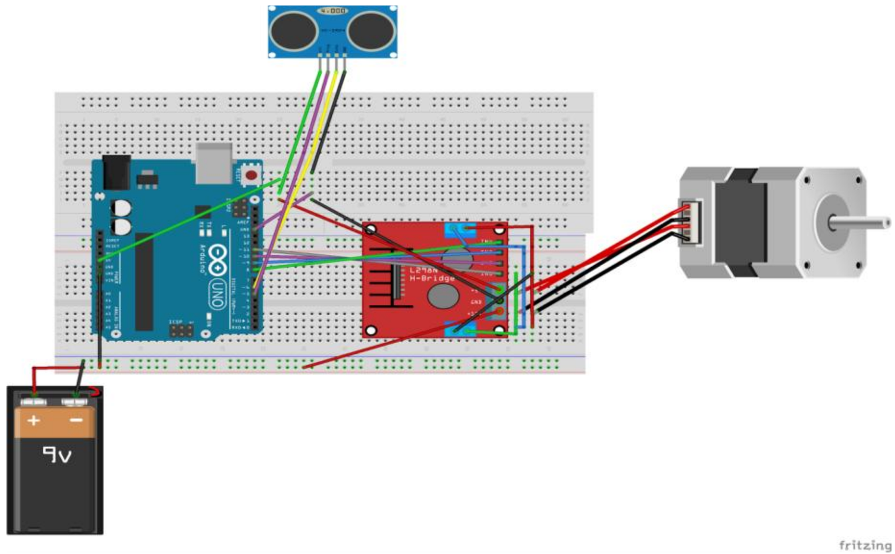


Figure #9 Electrical Components

The control systems are simplified with the block diagram shown in Figure #9. The load, released by the drone passes through an ultrasonic sensor. The sensor then sends information related to the package's velocity at that instance to the arduino. The arduino then controls the stepper motor by providing it with the necessary steps to turn in order to match the speed of the falling mass.

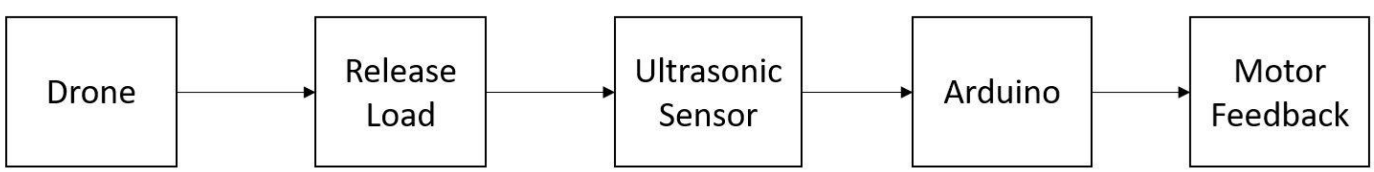


Figure #10 Control System Block Diagram

4. Modeling and Analysis

4.1 Statics

Although the chosen motor has enough holding torque, our system must remain in equilibrium at all times such as in the event of a power outage. A free body diagram for a continuous belt along a two pulley system is shown below in Figure #9. The sum of moments about point O must be 0 N-m at all times. The weight of our receiving plate, must therefore, match the counterweight of our assembly. The detailed analysis is shown below.

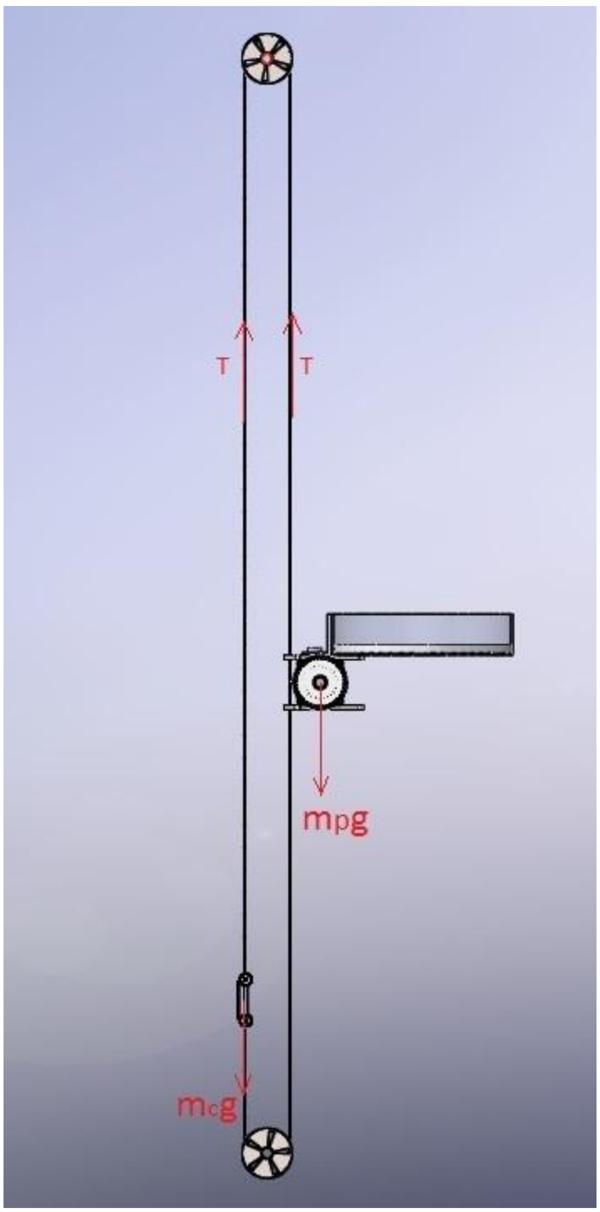


Figure #9 FBD of pulley system

$\sum F_x = 0$
$\sum F_y = 0$
$m_p = mass\ of\ receiving\ plate$
$m_c = mass\ of\ counterweight$
$T = tension\ of\ cable$
$g = 32.2. lbf/s^2$

$$m_p g + m_c g = 2T$$

$$T = \frac{(m_p + m_{c)g}}{2}$$

$$\sum M_0 = 0$$
$$T_c R - T_c R = 0$$

Estimated Mass of Receiving Plate = 14 lbs (SolidWorks-mass properties)

Tensile Strength of steel cables range from 120-14,000 psi; Thus, with the given weight, steel cables are not expected to yield and the system shall remain in equilibrium at all times.

4.2 Kinematics and Dynamics

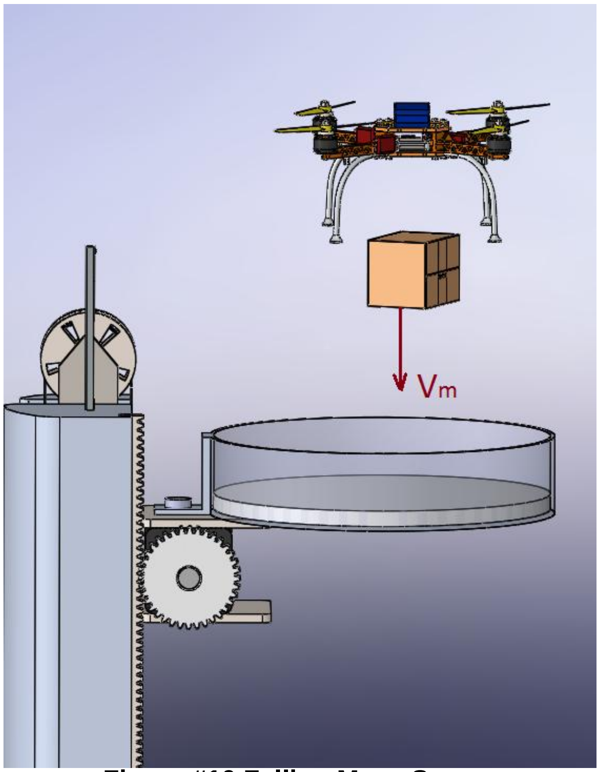


Figure #10 Falling Mass Scene

Kinematics

As the package is dropped by the drone, energy and kinematics equations are used to predict the approximate position and velocity of the falling mass.

$$mgh = \frac{mv^2}{2}$$

$$v = \sqrt{2gh}$$

$$h = 12.5\ feet$$

$$v = \sqrt{2 * 32.2\frac{ft}{s^2} * 12.5\ feet} = 28.37\frac{ft}{s} = 8.64\frac{m}{s}$$

Hence the velocity be slightly less than $8.64\frac{m}{s}$

The motor should accelerate the plate to attain a velocity of $8.50\frac{m}{s}$

4.3 Impact Analysis

As the mass is released by the drone, the receiving plate is accelerated downward to a point at which its velocity nearly matches the velocity of the receiving plate. The small difference in velocities results to a minimum average force exerted by the receiving plate upon contact by impulse momentum theorem.

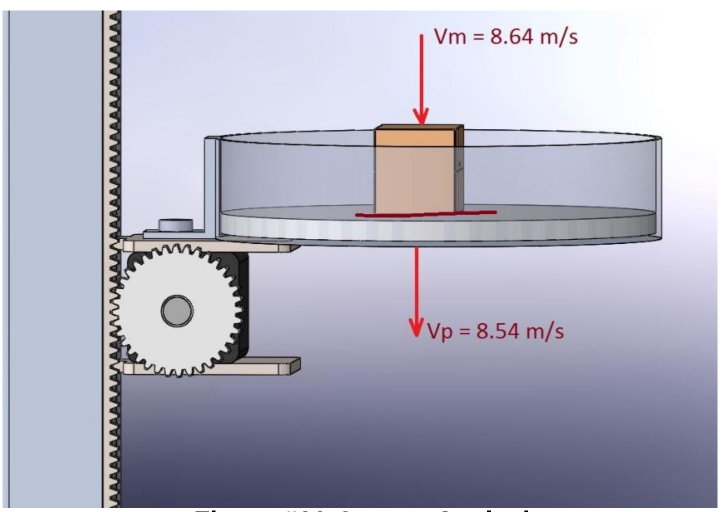


Figure #11 Impact Analysis

$$\bar{F} = m\left(\frac{V_f - V_0}{\Delta T}\right)$$

$$= 22.67\ kg\left(\frac{8.64\frac{m}{s} - 8.50\frac{m}{s}}{1\ s}\right) = 3.17\ N$$

4.4 Motor Power Requirements

This goal of this analysis is to calculate the motor power required to accelerate the receiving plate 8.50 m/s at the same instant at which the mass comes into contact with the plate. The approach used in this analysis converts the linear model to angular relationships in order to calculate torque and power that the motor must supply to meet the desired conditions.

Given:

$R_g(radius\ of\ gear) = 4.00\ in^2 = 0.00258\ m^2$

$I\ (moment\ of\ inertia\ of\ gear) = 4.065\ lb - in^2 = 0.001189\ kg - m^2$

$h = 12.5\ feet = 3.81\ meters\ (distance\ from\ the\ falling\ mass\ to\ expected\ location\ of\ receival)$

$$h = \frac{gt^2}{2}$$

Time elapsed from drop to contact

$$t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2 * 3.81\ m}{9.81\ m/s^2}} = 0.88\ s$$

$$V_p = at$$

Necessary linear acceleration of the receiving plate

$$a = \frac{V_p}{t} = \frac{9.64\ m/s^2}{0.88\ s} = 9.64\ m/s^2$$

$$a = R_g\alpha$$

$$\alpha = \frac{a}{R_g} = \frac{9.64\ m/s^2}{0.1016\ m} = 94.88\ rad/s^2$$

$$\omega = \frac{V_p}{R_g} = \frac{8.50\ m/s^2}{0.00258\ m^2} = 3295.57\frac{rad}{s}$$

$$\tau = I\alpha = 0.001189\ kg - m^2 * 94.88\frac{rad}{s^2} = 0.1128\ Nm$$

$$P = \tau * \omega = 0.1128\ Nm * 3294.57\frac{rad}{s^2} = 371.63\ W \approx 0.50\ hp$$

Thus, a 0.50 horsepower single shafted motor will be necessary for the chosen design.

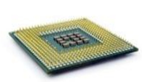
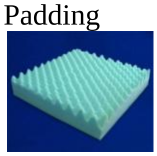
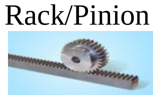
4.5 Vibration Analysis

The impact of the load as it is dropped down to the receiving plate shall be absorbed by polypropylene foam which will serve as the damper for the system. It is desired to minimize as much vibrations as possible it the smallest time interval. This corresponds to an overdamped case. Polypropylene foams, which are common in electrical device packaging, shall be used to dampen the impact of the load.

5. Approach to Solution

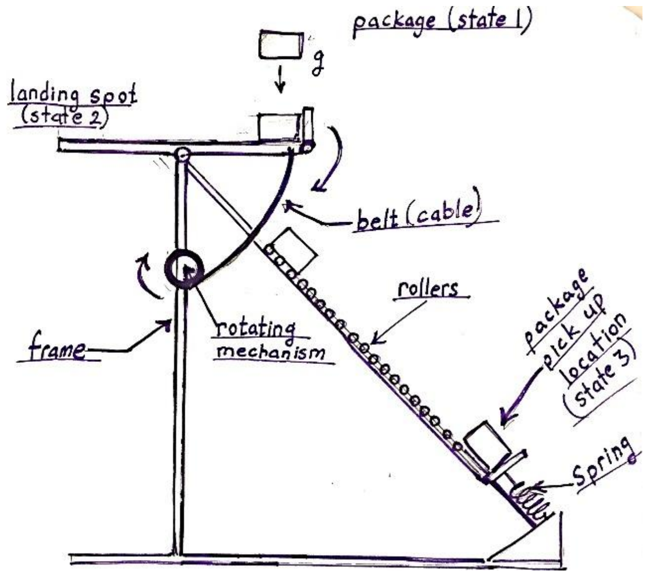
Various methods to accomplish the key features of our design were organized into a morphological chart as shown below. Majority of these methods were all considered in out early conceptual designs. A decision matrix was constructed to decide the most optimal design method upon which the final design was modeled.

5.1 Morphological Chart

SOLUTION						
	Function					
1	Process Signal	Analog Processor 	Microprocessor 	Reflective Optical Signal 		
2	Absorb Falling Impact	Foam Dampers 	Cushion Padding 	Styrofoam 	Bubble Wrap 	 Neoprene Pad
3	Lift or Lower	Pulley 	Rack/Pinion 	Hydraulic 	Chains 	Gravity Roller 
4	Provide Power	Electric Motor 	Human Power 	Battery 		

5.2 Early Conceptual Designs

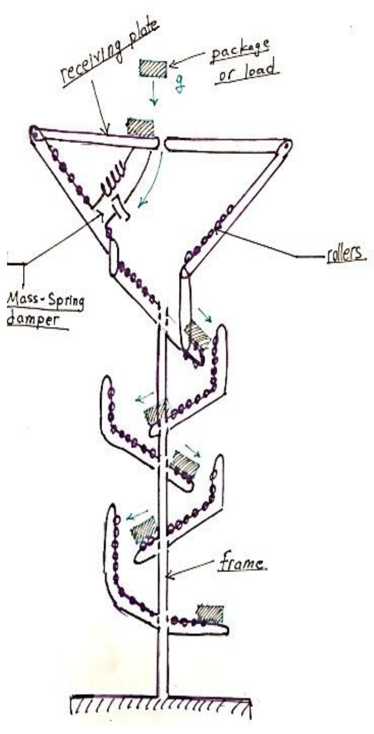
Design #1 *T-Pivot Mechanism*



Description:

The T-Pivot mechanism as shown above consists of a rectangular plate that pivots about its center. Cables are connected from one end of the receiving plate to a rotating motor powered by a battery. As the package is dropped from state 1 to landing spot at state 2, a natural response activates the motor, causing the receiving plate to rotate onto the 45° inclined beam. At this point the load will slide down with rollers that are mounted along the beam and be stopped by a spring at state 3 for recipient to pick up.

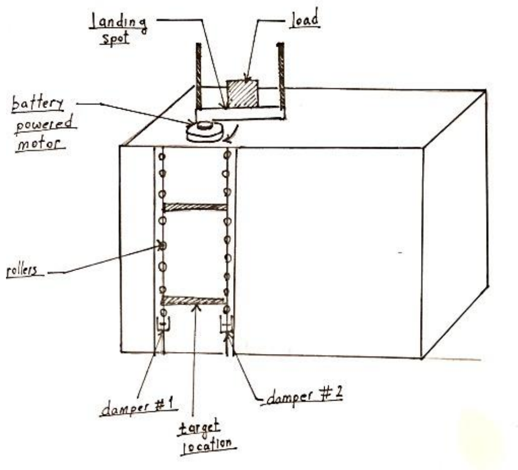
Design # 2 *Roller Guided System*



Description:

This mechanism uses a similar mechanism like design #1. It uses a mass-spring damper system to slowly catch the package. The package would drop on the receiving plate on either end and the mass-spring damper system would safely absorb the energy and slowly let down the package into a narrow funnel. The package would be guided along using rollers. To transport it from the top to the ground level where the consumer can pick up the package, a series of angled chutes with rollers on it are placed. The chutes and rollers would guide the package down going in a zigzag motion until it reaches the ground level.

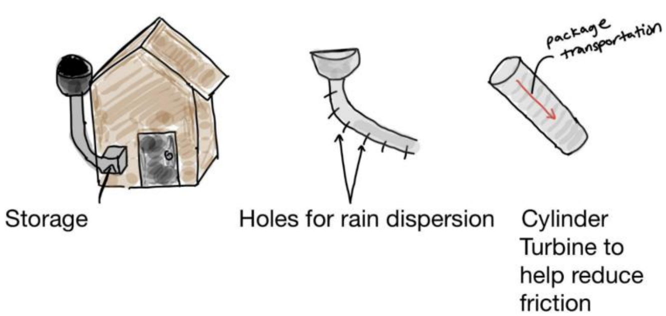
Design # 3 *Rooftop Receiver*



Description:

For the Rooftop Receiver mechanism, the load is dropped on the property illustrated by a landing stop. The package is then moved by battery powered motor attached to the top of the house. From there, rollers are used not only to reduce friction, so they can maintain a desired motion, but move the package towards a target location where dampers absorb the energy of the load.

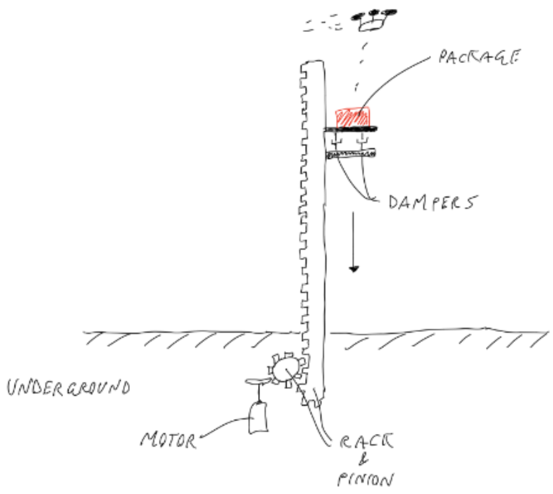
Design #4 *The Funnel System*



Description:

The mechanism is attached close to the front door of any average American home. At the top is the opening where the position is stationary. A pivot lid could be located at the top of the opening to help with absorption and allowing the package to go straight through for a simple entry. For the transportation a cylindrical tubing can be provided to help reduce friction as the package slides down to a safe container. Possible holes can be inserted along the cylinder to help disperse any unwanted particles.

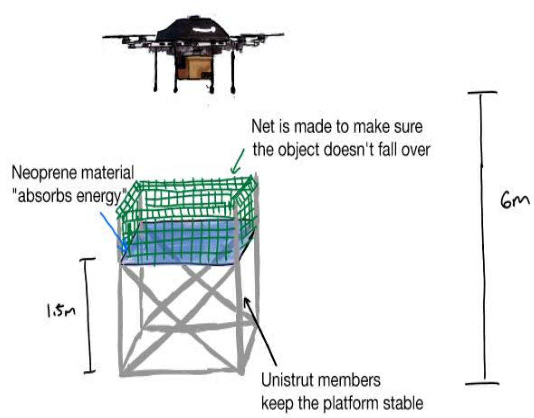
***Design # 5** Motor Driven Rack and Pinion*

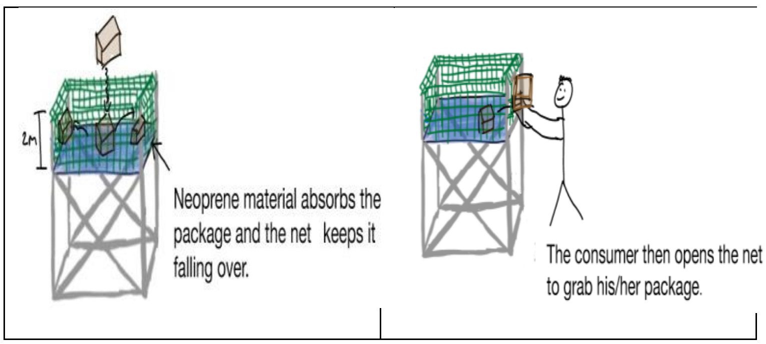


Description

In this concept the motor located below ground level utilizes the rack and pinion method for elevating the delivery tower. At the top of the tower sits the receiving plate supported by dampers for absorbing the impact.

***Design # 6** Elevated stand*





Description

When the object is dropped 6 meters high the absorbing pad made of neoprene will catch the package and a net will be attached to the upper two feet of the platform to prevent the package from dropping on the ground. This design will allow for any package up to 24 kilograms to land safety one and a half meters. The Neoprene pad is to be designed so it withstands any kinetic or potential energy produced from dropping the package. The net is a protection at the boundary of the Neoprene pad to prevent the box from falling into the ground. To grab the package the consumer will just need to open the net that is located 1.5 meters from the ground.

5.3 Decision Matrices

Absorbing Impact						
	Criteria	**Weight**	**Foam Dampers**	**Cushion Padding**	**Styrofoam**	**Polypropylene Pad**
1	**safety**	**10**	**D A T U M**	**S**	**S**	**+**
2	**cost**	**4**		**S**	**+**	**-**
3	**aesthetics**	**2**		**S**	**-**	**+**
4	**noise produced**	**5**		**+**	**S**	**+**
5	**reliability**	**9**		**+**	**S**	**+**
6	**durability**	**7**		**S**	**S**	**+**
7	**easy to replace**	**6**		**S**	**S**	**-**
8	**tolerance**	**3**		**S**	**S**	**S**
9	**sustainability**	**8**		**S**	**S**	**+**
10	**visibility**	**1**		**S**	**S**	**S**
	Total			**+2**	**0**	**+6**
	Weighted Total			**+16**	**+2**	**+37**

Lifting and Lowering Mechanism						
	Criteria	**Importance**	**Cable/Pulley**	**Rack and Gear**	**Chain**	**Gravity Roller**
1	**speed**	**7**	**D A T U M**	+	**-**	+
2	**safety**	**10**		+	**-**	**-**
3	**aesthetics**	**3**		+	**S**	+
4	**maintainability**	**2**		**S**	**S**	+
5	**range of motion**	**4**		**S**	**S**	**-**
6	**reliability**	**9**		**S**	**S**	**S**
7	**smoothness**	**8**		+	**-**	**S**
8	**noise level**	**5**		+	**-**	+
9	**easy to operate**	**6**		+	**S**	+
10	**tolerance**	**1**		**S**	**S**	**-**
	Total			**+6**	**-5**	**+2**
	Weighted Total			**+39**	**-34**	**+8**

6. Discussion of Results: Evaluation of Your Design

The Virtual and Physical Prototype of our design operate roughly the same way. The virtual prototype is used to show how our design would look like using a full scale model. It illustrates the design of the device with respect to a house, includes the padding used to catch the package as well as the sensor that detects it. The physical model is very scaled down and dictates how our device will operate in real life. The physical prototype looks more at the electrical components used to drive the motor, allowing us to create the intended design. Thus, it is to demonstrate the controls of our design as proof of concept.

One of the strengths for our design was the ability to control a stepper motor. We were able to make sure our motor matched the velocity of the falling package through arduino code. Therefore, we had little to no problems when it comes to implementing the correct velocity for the motor so no damage would come to the package. Strength for our design was the simulation for the virtual prototype. From our virtual we were able to notice from the start what changes needed to be done for our design before machining. It gave us a scope for what was possible when creating the best physical prototype in the time we had to make it. SolidWorks simulation was very beneficial in that it provided a blueprint for what we were trying to achieve with the physical.

Weakness came from the physical prototype for our design. Friction build up of the gear/rack when running the motor was one of the biggest problems we had. The motor would often get caught up with the gear and remain stationary. Another problem was the slippage of the gear along the rack. There were times when the gear would move along the rack to fast, so we had to provide more counter weight to prevent it from slipping. The amount of power needed to run the arduino, driver, motor, and ultrasonic sensor was sometimes short. We noticed that another 9V battery was to be applied in our system as well as a second arduino board for the ultrasonic sensor. This would allow for more efficient power to be distributed throughout the circuit. There was also a delay on the ultrasonic sensor which made it difficult to have our motor automatically run when an object passed through the sensor.

6.1 Test Procedures and Results

Having built our model we set out to test it. As shown by snapshot footages below, a test mass was dropped from a designated height. As the mass passed the ultrasonic sensor, the motor accelerated downward to match the speed of the falling mass. This demonstration was carried out multiple times and the system behaved as it was programmed. Our proof of concept therefore, in demonstrating the controls of our system, was turned out successful.

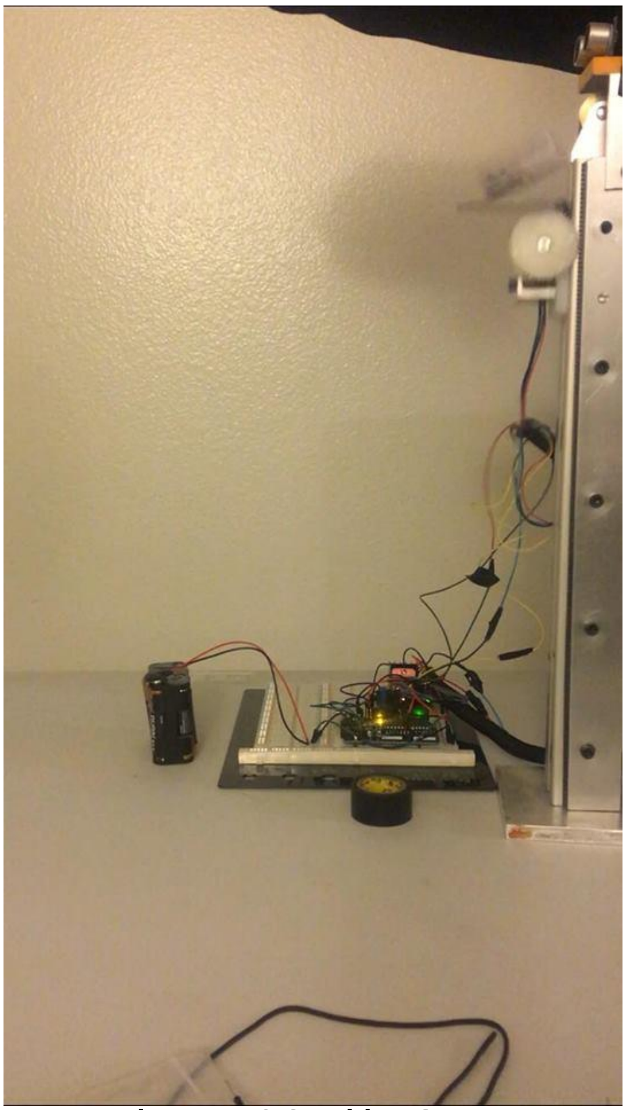


Figure # 12 Catching Scene

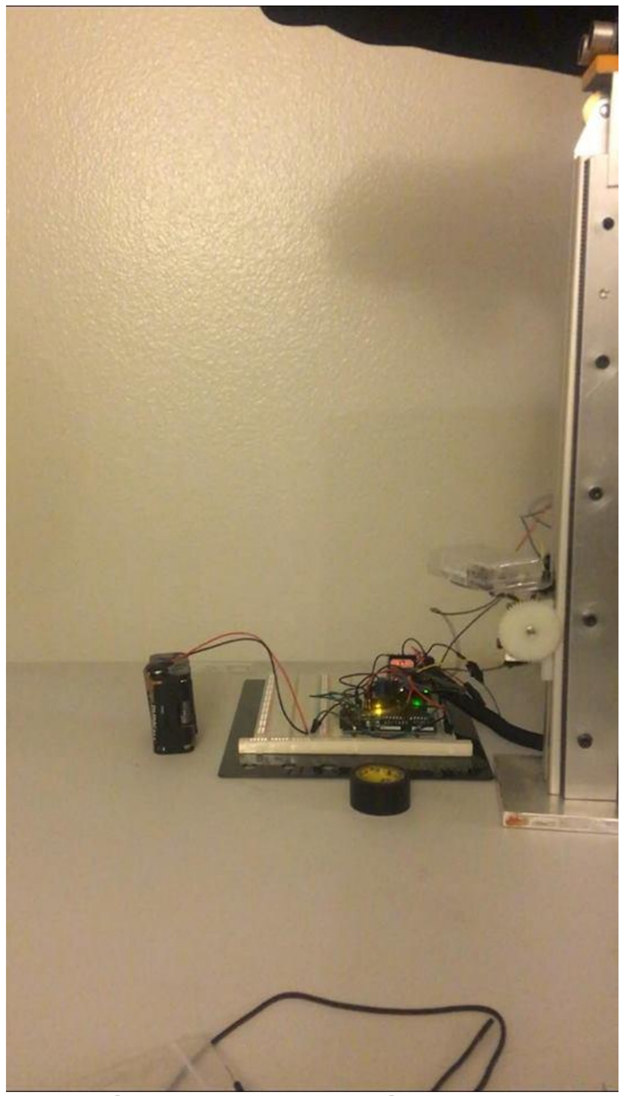


Figure #13 Transporting Scene

References

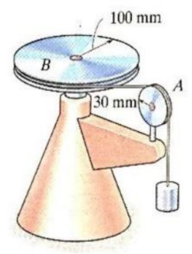
[1] S. S. Rao, Mechanical vibrations. Upper Saddle River, NJ: Pearson Prentice Hall, 2004.

[2] R. C. Hibbeler, Engineering mechanics: dynamics. Upper Saddle River, NJ: Prentice Hall, 2010.

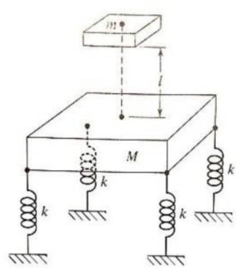
[3] L. Tatham, “Choosing the right extension ladder,” Browns Ladders, 27-Sep-2016. [Online]. Available: https://www.brownsladders.co.uk/blog/choosing-the-right-extension-ladder/. [Accessed: 15-Dec-2017].

Appendix

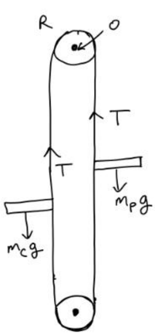
[1] R. C. Hibbeler, Engineering mechanics: dynamics.



[2] S. S. Rao, Mechanical vibrations.



[4] Sketch 1 2D Schematic



[5] Sketch 2 Free body diagram of chain-sprocket

```
Principal axes of inertia and principal moments of inertia: ( pounds * square inches )
Taken at the center of mass.
          Ix = ( 1.000,  0.000,  0.000)          Px = 2.461
          Iy = ( 0.000,  1.000,  0.000)          Py = 2.461
          Iz = ( 0.000,  0.000,  1.000)          Pz = 4.065

Moments of inertia: ( pounds * square inches )
Taken at the center of mass and aligned with the output coordinate system.
         Lxx = 2.461     Lxy = 0.000     Lxz = 0.000
         Lyx = 0.000     Lyy = 2.461     Lyz = 0.000
         Lzx = 0.000     Lzy = 0.000     Lzz = 4.065

Moments of inertia: ( pounds * square inches )
Taken at the output coordinate system.
         Ixx = 2.536     Ixy = 0.000     Ixz = 0.000
         Iyx = 0.000     Iyy = 2.536     Iyz = 0.000
         Izx = 0.000     Izy = 0.000     Izz = 4.065
```

```
#include <Stepper.h>

const int trigPin = 6;
const int echoPin = 5;

long duration;
int distance;

const int stepsPerRevolution = 200;  // change this to fit the number of steps per revolution
// for your motor

// initialize the stepper library on pins 8 through 11:
Stepper myStepper(stepsPerRevolution, 8, 9, 10, 11);

void setup() {
  // set the speed at 60 rpm:
  myStepper.setSpeed(300);
  // initialize the serial port:
  // put your setup code here, to run once:
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  Serial.begin(9600);
}

void loop() {|
  delay(1000);
  // step three revolution in the other direction:
  // put your main code here, to run repeatedly:
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);

  digitalWrite(trigPin, HIGH);
  digitalWrite(trigPin, LOW);

  delayMicroseconds(10);
  duration = pulseIn(echoPin, HIGH);
  distance = duration * 0.034/2;

  Serial.print("Distance: ");
  Serial.println(distance);
  delay(1
  );

  if(distance <= 10){
    for(int i = 0; i < 3; i++) //number of steps the motor takes for one revolution
    {
      // step one revolution  in one direction:
      //Serial.println("clockwise");
      myStepper.step(stepsPerRevolution);
      delay(1); // Delay in milliseconds for each step in the clockwise direction
```