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Multi-Purpose Aerial Drone for Bridge Inspection and Fire Extinguishing

25% Completed Report

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Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Raquel Remington, Ramon Cordero, Daniel Villanueva, and Larry March and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Abstract

1. Introduction

1.1 Problem Statement

There is an overall lack of multi-purpose aerial drones, or unmanned aerial vehicles (UAVs), around the world; and until recently, there was a lack of any feasible purposes of drones outside of military applications. Drone technology has advanced to the point in which portable devices are now economically priced enough for civilians to afford as well as easy enough to use with little to no training; however, the main draw back with drones even today is the lack of flexibility in purposes. Most civilian drones are marketed for surveillance purposes only, making the purchaser the one responsible for the labor and economics of any type of design changes to allow for different or more functions. The problem then evolves itself to how to make an economical UAV that can be used for more than one purpose?

1.2 Motivation

Currently there are many safety issues surrounding the inspection of bridges. In order to inspect a bridge for any signs of deterioration, a person must inspect said bridge directly. This poses a safety hazard due to the drafts under bridges that might result in failures of platforms on which the inspector is located, or even causing the inspector to lose balance and tumble off of the inspection platform. Even overhead power lines can pose risks to workers on platforms inspecting bridges since a knowledge in electrical safety is needed, which can complicate the situation when multiple crews are involved in a seemingly simple inspection. Even bodies of water below a bridge can pose significant safety threats. In this case, normal ground platforms used in inspections are no longer of any use, and suspended platforms can be extremely dangerous due to the lack of stability, yet it is still highly important to constantly monitor bridges for potential hazards because failures do occur.

Fire extinguishing can be even more hazardous in some instances. Fires in enclosed spaces cause for a decrease in visibility due to smoke production and have a potential to cut off any exit routes either immediately or later on, causing a potential for injuries or fatalities when exit routes are removed. Even so, fires in open spaces can be even more dangerous. Wild fires tend to spread extremely quickly, sometimes at speeds of 16-20 kmph, or 9.9-12.2 mph (Cheney), and rather sporadically since its movement is so heavily dependent on the wind, something mostly unpredictable. Due to the lack of predictability of wildfires, many deaths and injuries have occurred to both firefighters and civilians; thus, it is extremely imperative to find a safe alternative to direct fire extinguishing.

1.3 Literature Survey

Although drones have been around since the 1970s, it was not until recent that they became feasibly useful for more than military purposes (Whittle 1). Drone technology has advanced to the point in which portable devices are now economically priced enough for civilians to afford as well as easy enough to use with little to no training; some models even start around $599 as seen with the Parallax 80000 Quadcopter Kit. The main draw back with drones even today, though, is the lack of flexibility in purposes. One may pay $599 for a Parallax 80000, but will only have the opportunity to use it for surveillance purposes without major design changes, which can be expensive relative to purchase price. This is one of the main motivations to produce a multipurpose aerial drone for bridge inspection and fire extinguishing.

Although bridge inspections may not seem like the most dangerous job in the world, especially to the layman, injuries and fatalities have occurred while people have surveyed bridges. On January 23, 2013, Paul Schisler, an engineer for Shiavone Construction, fell to his death while inspecting the Aqueduct Bridge in New York (Heller). It is also not possible to end inspections on bridges to prevent injuries and fatalities of engineers and inspectors since bridges have a tendency to fail after a while, making it necessary to monitor a bridge to assign repairs to older or damaged bridges. According to "The National Bridge Inspection Program and the Highway Bridge Replacement and Rehabilitation Program," the Federal-Aid Highway Act of 1970, a result of the Silver Bridge collapse in 1967 during rush hour, which resulted in 46 deaths and many injuries, makes it mandatory for bridges to be periodically inspected for potential hazards. And in 1987, the Surface Transportation and Uniform Relocation Assistance Act made for additional requirements for underwater inspections of bridges due to a collapse at Schoharie Creek on I-90, which resulted in fatalities as well. The production of a drone that can inspect bridges for possible causes of failure is extremely important to inspectors as well as civilians who travel along the bridge; this drone will help to prevent any unwarranted deaths or injuries.

Fires also cause fatalities and deaths every year for both civilians and firefighters. There were twenty-two fire related deaths for on-duty firefighters in 2012 alone ("On-Duty Firefighter

Fatalities 1977-2012"), though injuries caused either directly or indirectly by fires have an even higher rate of incidence among firefighters. One of the most notable incidences of fatalities caused by wildfires occurred in Arizona in 2013. Nineteen firefighters died when a wildfire abruptly changed directions and surrounded them; although they all carried protective shelters for this very reason, the shelters proved not to be enough (Hanna). Civilian deaths and injuries are even higher, with 728 fire related fatalities that have occurred between January 1 and March 7, 2014 alone ("Residential Fire Fatalities in the News"), and that number will most definitely grow by the end of this year. This drone has the potential to prevent deaths of firefighters; and in the future, once the technology has been further developed, a prevention in deaths of civilians who would typically be waiting for the firefighters to arrive at the scene.

1.4 Discussion

The overall and paramount purpose of multi-purpose aerial drones, or unmanned aerial vehicles (UAVs), is to reduce the risk of injury or loss of life due to fire fighting and bridge inspecting. By implementing a cost effective approach to producing a UAV to extinguishing fires and inspecting bridges, manpower can be minimized, which will in turn increase safety and reduce the risks of injuries and fatalities involved in either tasks.

2. Project Formulation

2.1 Overview

There are many new techniques and methods formulated to make a certain task more feasible than the previous ones. These new methods are done by implementing a new design or updating a preceding design that will ultimately improve the function, efficiency, and cost of the system. This multipurpose drone will be designed in order to integrate and enhance certain robotic, electrical, aeronautical, and mechanical components in a former quadcopter. The major functions that this UAV will perform is to inspect bridges, extinguish small fires, and to be utilized as a testing mechanism for future research projects involving chemical compounds. This will be achieved by mounting a camera to the UAV that will transmit live footage through wireless video glasses, and installing a robotic device that will release fire extinguishing chemical grenades at a desired location. In order to accomplish these functions required, the design must take into account all the knowledge and elements used in the engineering field; particularly those in electrical, aerospace, and mechanical disciplines.

2.2 Project Objectives

Although new innovations are being conducted in the field of UAVs seen in today's generation, the standard UAV purposes are to be used for radar and navigate from elevated heights without the need of a human pilot. The objective is to augment the functions that a standard UAV performs in today's society by installing cameras that can transmit video recordings to wireless video glasses, and manufacture and design a release mechanism that will be used for testing and fire extinguishing purposes. In the engineering perspective, the intentions of this project are to maximize the UAV's overall efficiency and minimize the cost by taking into account material, mechanical, aerospace, and electrical engineering methods that will improve the UAV's functions. In the environmental perspective, the objective is to make our UAV safe for all living creatures and the planet by using material that can be recycled and reused without polluting the land, water, and air. Lastly, the intentions of this project are to make this UAV on a global production that will be used to aid all people and societies that have bridges, fires, and research purposes in the chemical field. This drone will be able to extinguish fires at places where firefighters cannot reach, make it safer to inspect bridges without putting a person's life in danger by having to inspect them at high altitudes, and be used to advance research on chemical substances.

2.3 Design specifications

The current design is a multipurpose quadcopter, also known as a quad-rotor helicopter. A quadcopter is also qualified as a rotorcraft which is a heavier than an air machine that utilizes lift generate by its wing, which are also called rotor blades that revolve around a mast. Specifically for this design, there will be four rotor blades that will generate lift; hence, the name quadcopter. Quadcopters utilizes two sets of identical propellers in fixed locations. Two of the propellers will spin clockwise, and the other two will spin counter-clockwise to negate the torque felt by the quadcopter.

The quadcopter has obtained quite a reputation as a UAV system in the engineering field mainly because of system's simplicity in terms of function and set up, which makes it a desirable platform to work on. This particular design will perform different tasks; one of which is bridge inspection, where it will utilize an onboard camera system to send feedback to the operator about the conditions of the part of the bridge currently under inspection, as well as an onboard fire extinguishing system to control small scale fires that cannot otherwise be reached by a human.

Figure 1: Example of a Quadcopter Model

The quadcopter is mainly known for its ability to carry a payload, an ability which will be utilized to carry a small firefighting agent bomb, which will be dropped onto the targeted fire. The extinguishing agent will be dropped using a small scale dropping mechanism.

Figure 2: Release Mechanism for Chemical Extinguisher

The payload for this quadcopter is also a key factor in this design since the secondary function is to extinguish fires. The payload has to consist of a fire-extinguishing grenade. The grenade is spherical in shape, and has a mass of 1.3 kilograms. It is filled with fire extinguishing chemicals that will automatically activate once in the presence of a fire.

Figure 3: Fire Extinguishing Grenade

2.4 Constraints and Other Considerations

The first apparent constraint to the design is that the chemical extinguisher can ideally only extinguish a fire of volume 9.5 m^3. This would be ideal for indoor fires (i.e. in a house or tall building), which makes a UAV an ideal platform to enter through windows to drop the fire extinguishing grenades. When releasing the grenade outdoors, the grenade can only be realistically placed on the ground as a preventive measure against fires. Furthermore, when dropping the grenade in an open area the area cannot be on fire as the pilot runs the risk of losing control of the quadcopter due to severe updrafts associated with larger fires, much like wildfires.

When flying underneath bridges, the quadcopter runs the risk of flying through wind drafts, which can increase the chances of it colliding with the surfaces of the bridge or losing control; therefore, operators must be well trained when in operation of the quadcopter. Also, good calibration of the altitude as well as the proximity sensors will reduce the chance of collisions; therefore enabling more accurate acquisition of measurements and observations in an easier fashion.

2.5 Discussion

Optimization of the multi-purpose aerial drones, or unmanned aerial vehicles (UAVs) is one of key elements to overcome the draw backs of this design. By manipulating the UAV to accommodate for the release of a fire extinguishing grenade at the exact location will definitely be a great asset to achieving one of the goals: to reduce the loss of life and prevent injuries to anyone. Furthermore, the continuing practice of getting familiarized with the maneuvering of the UAV will help provide a greater accuracy of the information obtained while performing inspections on bridges. In the optimization of the UAV, it would be beneficial to introduce a proximity sensor to be able to warn the operator of the proximity of the UAV to the bridge, helping to reduce the chance of collisions with the quadcopter and bridge.

3. Design Alternative

3.1 Overview of Conceptual Design Alternative

In order to accomplish the necessary functions that the UAV Quad-copter will execute, three main designs were chosen. These designs involve the UAV Quad-copter’s main components that will be optimized, which are the release mechanism and camera. The release mechanism designs are made in order for the UAV Quad-copter to discharge a chemical ball at a selected location to extinguish flames or for testing and research motives. Additionally, a camera is to be installed on top of the UAV Quad-copter that will be utilized for recording, photograph, and inspecting purposes. The camera will be predominantly used to inspect bridges, buildings, and other structures that engineers evaluate. These two key characteristics of the UAV Quad-copter are the focal points to the designs demonstrated in the subsequent sections.

3.2 Design Alternate 1

The first design illustrates a robotic arm in the form of a claw. The robotic arm is designed in a manner that it would open and close its claws from an electronic signal given by the user who manages the Quad-copter's remote control. This robotic arm is able to close its claws until their tips touch, which means that the user must be careful to close the claws just enough that it will hold the fire extinguishing ball and not compress it in excess of exploding it. The robotic arm is to acquire its power by absorbing part of the batteries output voltage that is also absorbed by the propellers to make the UAV Quad-copter fly. This means that the robotic arm must be designed in a manner in which it will not require much power from the battery source in order for the UAV to fly longer. The robotic arm will be composed of aluminum material for the two reasons of it being a lightweight material that is known to be unproblematic to manufacture. One of the main disadvantages of this design is the fact that it would only be able to carry one fir extinguishing ball at a time, which will make it required to come back to the user in order to continuously reload it with a new fire extinguishing ball.

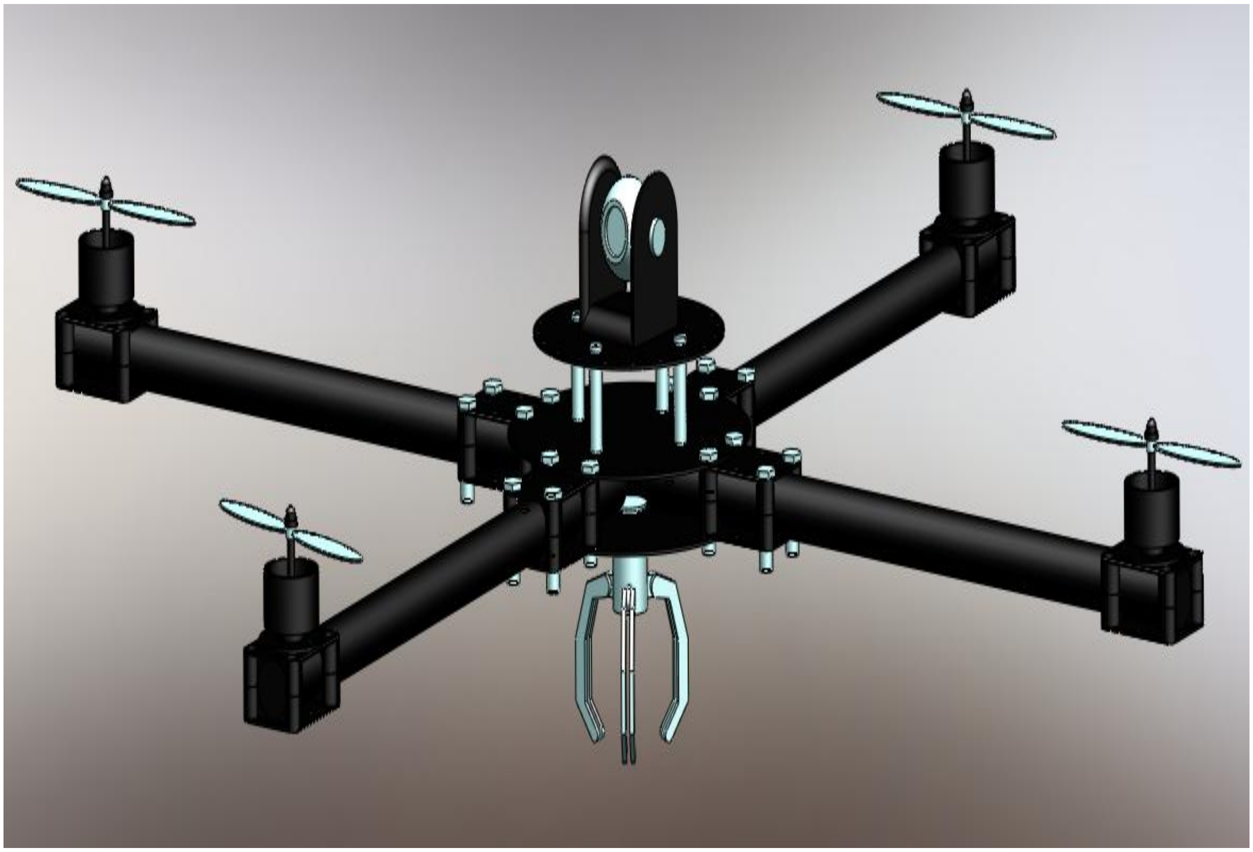


Figure 4: Design Alternative 1 (View 1)

Figure 5: Design Alternative 1 (View 2)

3.3 Design Alternate 2

The second design alternative is to build a cylindrical shape cage structure. The benefit of this structure is that it will be able to carry more than one fire extinguishing ball. This is essential because more flames can be extinguished at a faster rate, which is a vital when an emergency fire hazard occurs. The cylindrical release mechanism will be designed in order to hold and release the fire extinguishing balls by the signal given by the remote control of the entire system. This involves some mechatronics components such as a stepping motor, which will be used to both hold and release the fire extinguishing balls. The stepping motor will rotate at a total angle of 30 degrees counterclockwise to release the first ball, and then be programmed to rotate 30 degrees clockwise until it reaches its initial position in order to catch and hold the second ball in place. The same procedure will be used to release the second ball and any other balls that the cylindrical mechanism can contain. For weight purposes, this release mechanism will just be containing two fire extinguishing balls and will be made out of carbon fiber because of its tough and lightweight properties.

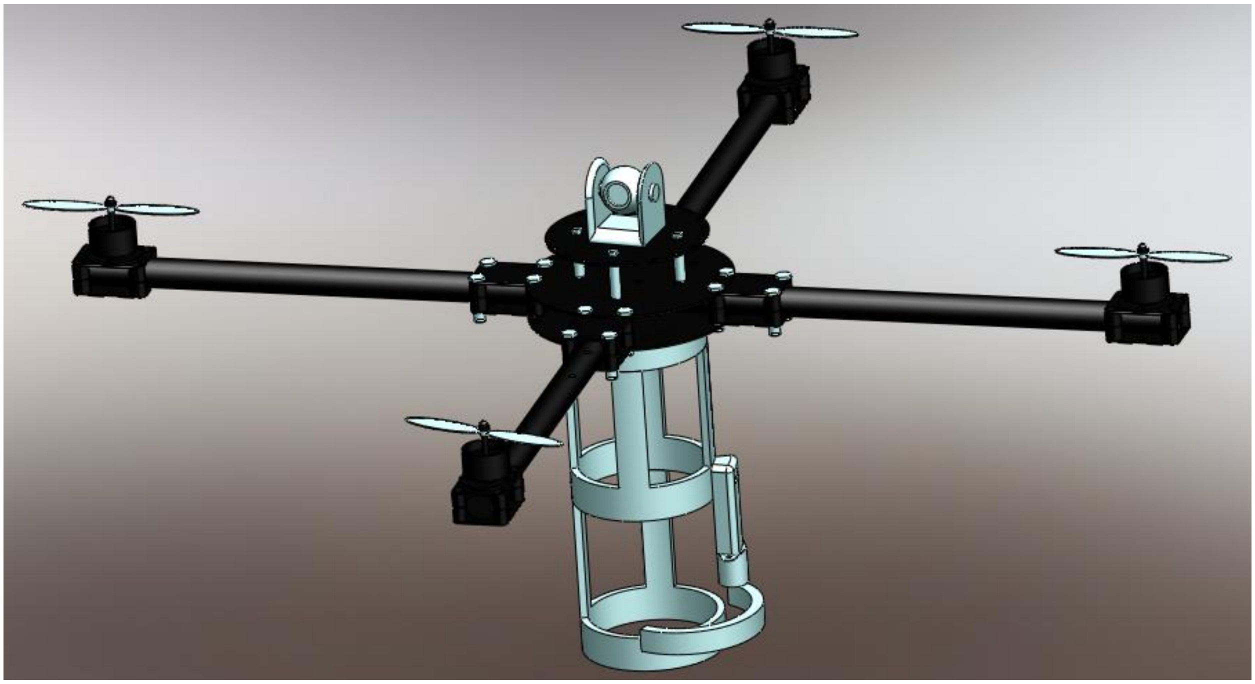


Figure 6: Design Alternative 2 (View 1)

Figure 7: Design Alternative 2 (View 2)

3.4 Feasibility Assessment

3.5 Proposed Design

3.6 Discussion

4. Project Management

4.1 Overview

In order to have a successful project, the division of task and responsibilities among the team members is necessary for an orderly and organized work environment in which the developing system at hand can be completed. Making sure that every team member withholds a certain level of dedication and determination, the division of the work load gave way to milestones in which the team members can predict the due date for the project based upon which of these goals have been achieved first. This gives way to an optimized team efficiency, one that can get the work load done in the required time. Therefore, with these facts in mind, the expected date for the quadcopter to be fully optimized and completed will be by the beginning of December 2014 according to Table 1. This will give more time to test the quadcopter's abilities and make adjustment to the system in order to make it more efficient in the specific tasks that it must complete. Certain parts may still need to be ordered for the optimization to be made, but as soon as the planning process has been completed the building task will commence.

4.2 Breakdown of Work into Specific Tasks

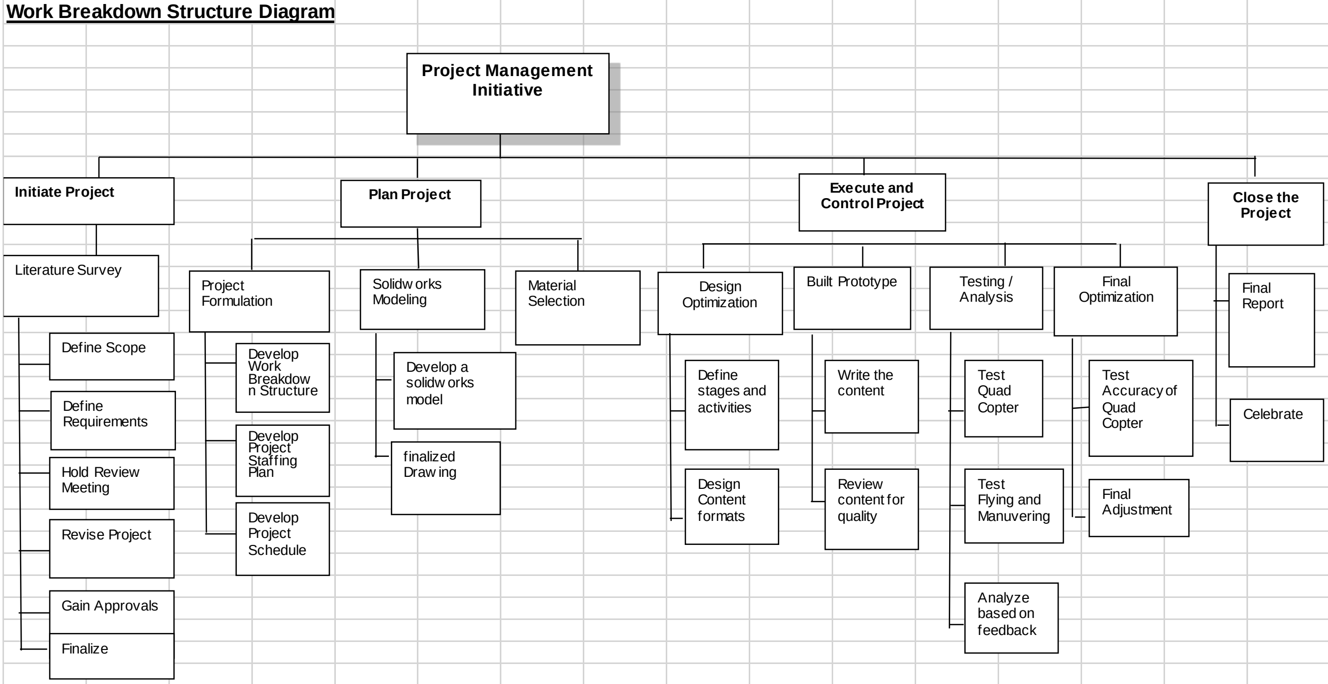
Work Breakdown Structure Outline

Project Management Improvement Project

1	**Initiate Project**
1.1	**Literature Survey**
1.1.1	Define Scope
1.1.2	Define Requirements
1.1.3	Hold Review Meeting
1.1.4	Revise Project
1.1.5	Gain approvals
1.1.6	Finalize
2	**Plan Project**
2.1	**Project Formulation**
2.1.1	Develop Work Breakdown Structure
2.1.2	Develop Project Staffing Plan

2.1.3	Develop Project Schedule
2.2	**Solidworks Modeling**
2.2.1	Develop a solidworks model
2.2.2	finalized Drawing
2.3	**Material Selection**
3	**Execute and Control Project**
3.1	**Design Optimization**
3.1.1	Define stages and activities
3.1.2	Design Content formats
3.2	**Built Prototype**
3.2.1	Write the content
3.2.2	Review content for quality
3.3	**Testing / Analysis**
3.3.1	Test Quad Copter
3.3.2	Test Flying and Maneuvering
3.3.3	Analyze based on feedback
3.4	**Final Optimization**
3.4.1	Test Accuracy of Quad Copter
3.4.2	Final Adjustment
4	**Close the Project**
4.1	Final Report
4.2	Celebrate

Work Breakdown Structure Diagram



4.3 Organization of Work and Timeline (Timeline for Senior Design Organization and Senior Design time frame)

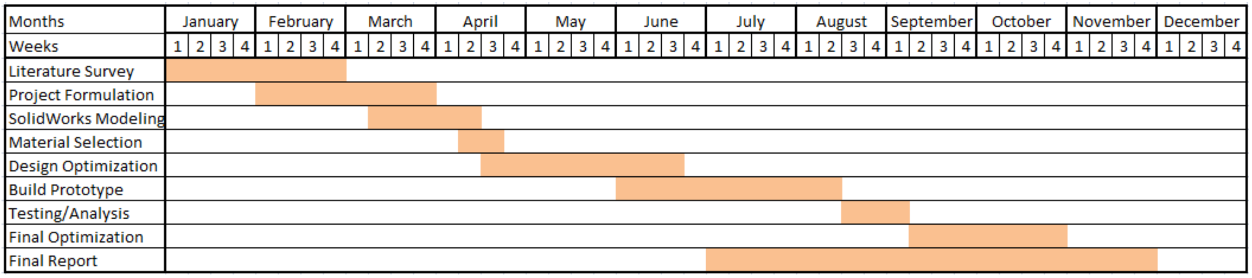


Table 1: Timeline

4.4 Breakdown of Responsibilities Among Team Members (Indicate Each Member's Major and Support Roles for Each Task)

It is necessary in any project to assign tasks to specific individuals or groups of individuals in order for the total project to be most efficient. The majority of the tasks in this project are going to be group efforts as seen in Table 2. It is necessary in this project to have individual inputs from every group member on the designs, parts, prototype builds, etc. There are a few tasks in which one or two team members may be better apt to completing these tasks; and accordingly, those individual tasks have been distributed based on the ability level of individual team members, although it may be necessary to eventually change the distribution of workloads or have more than one or two people working on specific individual tasks.

Task	Team Member(s)
CAD Modeling	Ramon C.
Prototype Design	Raquel R., Daniel V. Larry M., Ramon C.
Optimizations of Design	Raquel R., Daniel V. Larry M., Ramon C.
Parts Purchasing	Raquel R., Daniel V. Larry M., Ramon C.
Prototype Assembly	Raquel R., Daniel V. Larry M., Ramon C.
Testing	Raquel R., Daniel V. Larry M., Ramon C.
Analysis of Test Results	Raquel R., Daniel V. Larry M., Ramon C.

Simulations	Daniel V., Larry M.
Cost Analysis	Raquel R.
Second Iteration of Design	Raquel R., Daniel V. Larry M., Ramon C.
Final Assembly	Raquel R., Daniel V. Larry M., Ramon C.

Table 2: Tasks

4.5 Patent/Copyright Application

4.6 Commercialization of the Final Product

4.7 Discussion

5. Engineering Design and Analysis

5.1 Kinematic Analysis and Animation

5.2 Dynamic/Vibration Analysis of the System

5.3 Structural Design

5.4 Force Analysis

5.5 Stress Analysis

5.6 Material Selection

5.7 Design Based on Static and Fatigue Failure Design Theories

5.8 Deflection Analysis

5.9 Component Design/Selection

5.10 Finite Element Analysis

5.11 Design Overview

5.12 Cost Analysis

5.13 Discussion

6. Prototype Construction

6.1 Description of Prototype

6.2 Prototype Design

6.3 Parts List

6.4 Construction

6.5 Prototype Cost Analysis

6.6 Discussion

7. Testing and Evaluation

7.1 Overview

7.2 Design of Experiments - Description of Experiments

7.3 Test Results and Data

7.4 Evaluation of Experimental Results

7.5 Improvement of the Design

7.6 Discussion

8. Design Considerations

8.1 Assembly and Disassembly

8.2 Maintenance of the System

8.2.1 Regular Maintenance

8.2.2 Major Maintenance

8.3 Environmental Impact

8.4 Risk Assessment

9. Conclusion

9.1 Conclusion and Discussion

9.2 Patent/Copyright Application

9.3 Commercialization Prospects of the Product

9.4 Future Work

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