


Senior Design Project

Final Report

# Color Tracking Smart Camera:

# 3DoF Pan-Tilt System

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# Project Summary

The number of degrees of freedom (DoF) a system has is crucial to the system's technical abilities and its function. The more DoF a system has, the larger range of motion it can cover and hence its scope of application and function greatly increases. For example, a robot arm with 6 DoF will be able to cover greater scope of application than one with only 3 DoF. Implementing more DoF for a system however, is a difficult task which will increase the complexity of the system. Hence many products are designed in such a way that reduces the need of more DoF by means of control and post-processing. An example for such a case is a camera system with 2 DoF with the ability to post-rotate the captured image/video. Various 2 DoF and 3 DoF camera systems exist in the market today and some examples are surveillance cameras (2 DoF) and gimbals (3 DoF). However, except for gimbals, there are not many examples of 3 DoF camera systems in the market that cover these 3 axes.

Hence this project will focus on camera systems with 3 DoF with the ability to use its scope of motion to track objects and to also counteract large movements for stable tracking. Additionally, this project will be designed to be attached to a moving object such as aerial or land vehicles where unexpected movements due to wind or uneven terrain can cause disruption while tracking an object.

The aim of this project is to build an effective camera system that can track objects in any direction. To track object, rather than implementing complex algorithms for object detection, it would be better to detect color of an object.

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2.3.6 Patent #: 10-2018-0060634

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# Chapter 1. **Introduction**

## 1.1 Preface

This report lays out the entire design of making a 3 DoF system with an ability to use its scope of motion to track objects and to also counteract large movements for stable tracking. The introduction explains the problem and its usefulness in the industrial fields, and even for daily lives. The objective, challenges, project timetable, and responsibilities are listed here as well.

## 1.2 Motivation

As technology advances, humanity is preparing to explore and colonize other planets. Elon Musk, the CEO of Tesla, has said that his plan to establish a permanent colony on Mars will eventually allow humanity to become not just multi-planetary but also interstellar. Numerous companies and governments are putting a lot of money on a Mars colonization project.

Before humanity lands on Mars, it is essential to investigate whether the planet has a suitable environment for life. In order to find this out, rovers could be sent to Mars and perform their missions. However, the surface of Mars is very uneven and bumpy, which makes it difficult for rovers to perform their missions such as following or targeting specific objects. Attaching an autonomous 3DOF camera system to a rover would be a solution to this problem since it has all three (pitch, yaw, and roll) motions, which not only enables the rover to track the object quickly and precisely but also, make a rover operate autonomously. This system could also be attached to various applications. For example, attaching the system to a tank will enable a tank to be an autonomously operating system with a quick and precise targeting system so that the soldiers won’t have to risk their lives. It could also be attached to a firefighting drone so that it can provide a clear image of a source of fire quickly and precisely without any fluctuations.

Building a 3DOF system would be beneficial compared to a 2DOF system with software adjustment since a 2DOF system with software adjustment cannot respond as quickly as a 3DOF system if there is a significant movement or turbulence in the system. Also, building a 3DOF system contains more mechanical aspects while a 2DOF system is more based on coding. There are already many different designs of a 2DOF system in the market but there is no system built with a 3DOF system. Therefore, it would be sensational if a 3DOF system with a compact size and lightweight could be built.

## 1.3 Problem Statement

Previous gimbal systems for cameras that are in the market are mostly 2-DOF systems, and there are a lot of 2-DOF products as well. For the last axis (roll axis), object tracking adjustment is done by using complex software rather than using the mechanical solution. However, a 2-DOF system with software adjustment is fragile to external environments such as complex movements or strong disturbance, which require too much data processing. Also, this leads to a larger and heavier machine system, making it difficult for drones or unmanned vehicles which require a comparably lighter system. Consequently, through this machine design, it is expected to have significant meaning in building a mechanical 3-DOF system, reducing errors in calculations of large data.

## 1.4 Solutions to Problem Statement

### 1.4.1 Main Challenges

The challenging aspect of the project is that there are unexpected movements of the object that needs tracking. For example, for an object that is moving at a high speed, the tracking

may not be accurate depending on the performance of the camera. Since the system is using VGA resolution(640 * 480 pixel), the quality of image is not appropriate for tracking high-speed objects.

Our design focuses on making the bottom part turn 360 degrees, so as the design turns 360 degrees, the wires also get twisted when the bottom part of the servo motor is turned. If the design continues to spin 360 degrees and the wires are twisted, the wires will eventually be pulled out or broken, which can lead to an overall failure of the design.

### 1.4.2 Approach to Constraints

Since the resolution of the camera is too low for the software to accurately recognize the object, it is necessary to simply use a camera with high resolution to solve this problem. However, most high-resolution cameras are USB A-type, so our system using Arduino is not suitable, so we can solve the problem by converting the microprocessor into a Raspberry Pi and configuring it as an HD-quality webcam.

In order to solve the wire tangling problem, the first iteration of pulling the wires out is applied by making a hole in the center of the design so that the wires are not connected out, but connected inwards so that they do not twist even after 360 degrees of rotation.

### 1.4.3 Advantages over Prior Art

Microprocessors such as raspberry pi and high-resolution webcams help improve overall design functionality by increasing recognition as well as very fast data processing.

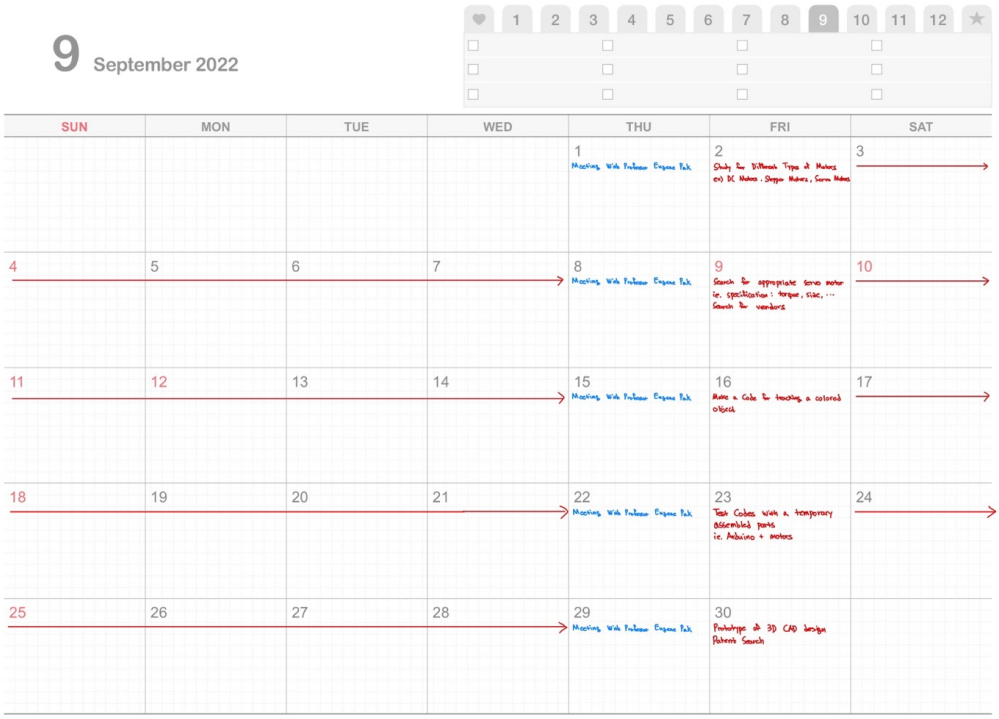
Also, by making a hole in the middle of the design so that the wires are connected inside, the wires do not twist even if the design rotates several times, so there is no problem of breaking the legend, reducing the malfunction of the design.

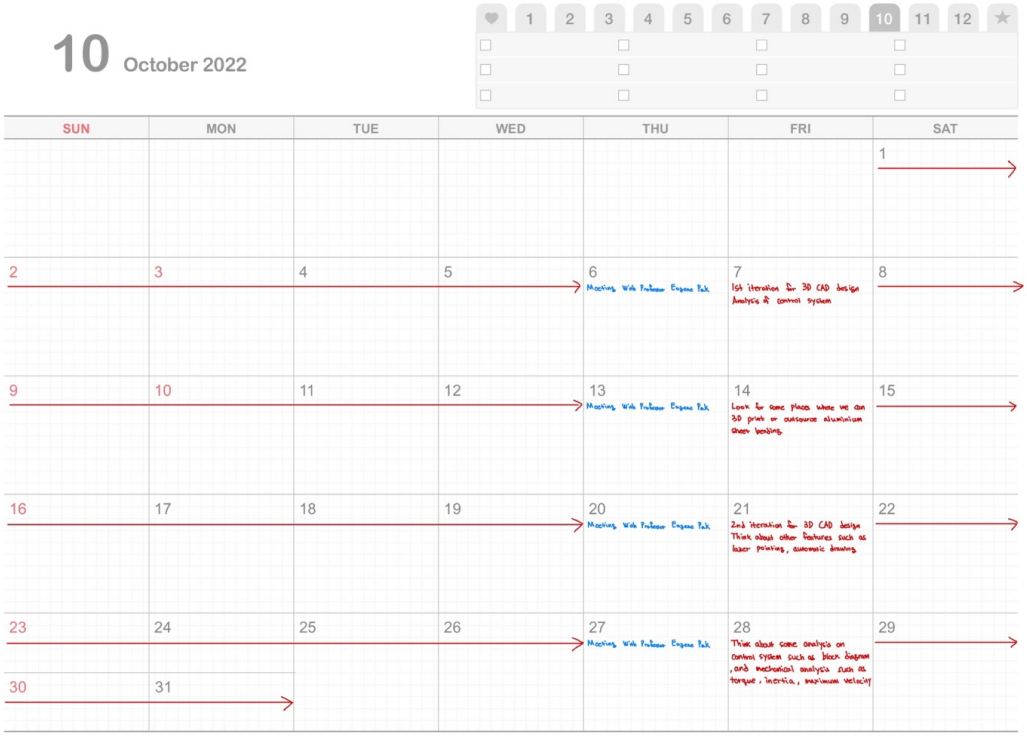
### 1.4.1 Impact

Replacing low-recognition cameras with high-resolution webcams and microprocessors as well as raspberry pi, it can be achieved slightly better recognition and faster data processing, which will eventually enhance design capabilities, enabling faster object recognition and tracking.

Also, by making a hole in the center of the design and connecting the wires inside, the wires can be prevented from getting twisted no matter how many times the design goes around, so there is an improvement in the duration related to the design.

## 1.5 Time Table for Key Milestones



# 11 November 2022

| SUN | MON | TUE | WED | THU | FRI | SAT |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 Meeting With Professor Eugene Park | 4 Printing out the 3D CAD design so that we have an actual physical design. Give two or more iterations to improve the 3D CAD design | 5 |
| 6 | 7 | 8 | 9 | 10 Meeting With Professor Eugene Park | 11 Demonstration whether the design actually works. Apart from autonomous control, make a system that can control the design with a joystick | 12 |
| 13 | 14 | 15 | 16 | 17 Meeting With Professor Eugene Park | 18 Adjustments with Cubes so that the Design would be operating continuously while the input is given | 19 |
| 20 | 21 | 22 | 23 | 24 Meeting With Professor Eugene Park | 25 Finalizing codes and 3D CAD design. Make sure the design to move without any issues Start writing a report | 26 |
| 27 | 28 | 29 | 30 | | | |

# 12 December 2022

| SUN | MON | TUE | WED | THU | FRI | SAT |
|---|---|---|---|---|---|---|
| | | | | 1 Meeting With Professor Eugene Park | 2 Prepare for the final presentation | 3 |
| 4 | 5 | 6 MEC441 Final Presentation | 7 Finalizing the Final report | 8 | 9 | 10 |
| 11 | 12 | 13 | 14 | 15 | 16 Submit the final report | 17 |
| 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 25 | 26 | 27 | 28 | 29 | 30 | 31 |

## 1.6 Group Member Expertise & Responsibilities

**Table 1.6.1** Group Member Expertise

| Member | Expertise |
|---|---|
| Hojung Lim | Team Leader: organizing team meeting, managing the schedule<br>Coding: implementing codes into a system |
| Hakyeong Lee | CAD Design: implementing 3D CAD design for the project |
| Junbin Choi | Analysis: analyzing mechanical concepts used in the design |
| Yongeun Kim | Analysis & Design Support: calculation made with mechanical analysis and helped making 3D CAD design |

**Table 1.6.2** Group Member Responsibilities

| Member | Responsibilities |
|---|---|
| Hojung Lim | Make codes that control the system<br>Assemble the parts and test it with codes<br>Make sure that parts delivered on time |
| Hakyeong Lee | Look for appropriate vendors for motors<br>Find fine motors that can be used for the system |
| Junbin Choi | Look for some useful code sources that can be implemented in the system<br>Patent search<br>Organizing the report |
| Yongeun Kim | Make sure 3D printing working properly<br>Patent search<br>Organizing the report |

# Chapter 2. **Background Research**

This section discusses the current market for 3 DoF and 2 DoF pan-tilt systems in industrial fields and consumer products.

## 2.1 Market Research

The existing camera gimbal system in the market is in the form of a two-axis based (fan-tilt), and the other axis is not usually considered for design. Mechanically, the three-axis system becomes considerably more complicated than the two-axis system, and the weight of the entire system is increased. Most of the many camera gimbal systems in the actual market are very simple manual operating systems considering their weight, and even for military/strategic systems, 2-axis products account for the majority, or 3-axis products are very heavy and expensive. In addition, if compensation for mechanically deficient design is trended with software or data processing and control systems, this design aims to lose batteries for processing huge amounts of data, weight and size of the system, and to verify its excellence through miniaturization and simplification. Through this, it is difficult to fix the position of a drone, etc., and it is intended to pursue its versatility by using it for unmanned vehicles with a small load.

## 2.2 Existing Models



**Figure 2.2.1** Two-Axis Machine Gimbal System and Camera Installed On a Ship or Ship

Ships or Traps - Many cameras are used on the deck of ships and battleships to detect or closely track targets. Usually, the deck of a ship uses a mechanical 2-axis gimbal to compensate for fluctuations by waves or disturbances, or for ship anchorage, but these gimbals are very heavy, expensive, and are only used in special vessels, making them very less versatile. This can be made lightweight and miniaturized, and can be widely used for more general ships and fishing boats.

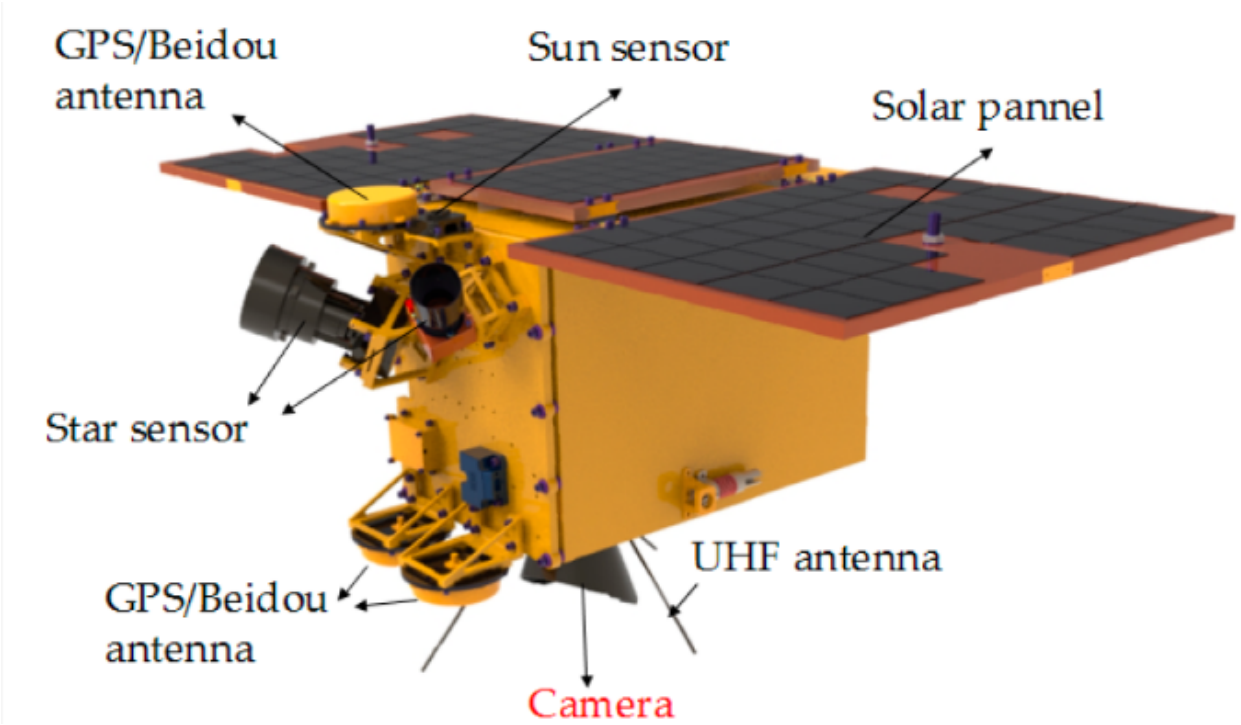



**Figure 2.2.2** Luojia 1-01 Satellite

Satellite systems - In the market there are cameras which is existing in the satellites, but they are not a 3DoF system. However, 3DoF System would be effective in space. In space, satellites orbiting around the Earth are not gravity-free, so they have a lasting force of motion even by very fine forces or disturbances. There is a very precise telescope-like system in the satellite, which can be used for continuous location tracking or target monitoring by locking the image of a target point at a location on Earth. This 3-axis gimbal is expected to be used in real-time and continuous fine tracking regardless of the movement, rotation, and movement of the mother ship satellite system.



**Figure 2.2.3** Example of a Passive Machine Biaxial Gimbal

Small unmanned vehicles - Small unmanned vehicles such as drones are very difficult to hover in a fixed position during flight due to external forces caused by air currents or external forces generated by lift from drone wings. To overcome this, instead of fixing the position of the aircraft to stop flight, a system can be considered in which the unmanned vehicle itself moves, but the camera of the vehicle locks the shape or color of the target point and tracks it regardless of the unmanned vehicle's movement. By utilizing this, it can be used for fire drones that are expected to have severe external forces.

## 2.3 Patent Research

### 2.3.1 Patent #: US 9030306B2

Title:APPARATUS AND METHOD FOR 3 DEGREE OF FREEDOM (3DOF) TACTILE FEEDBACK

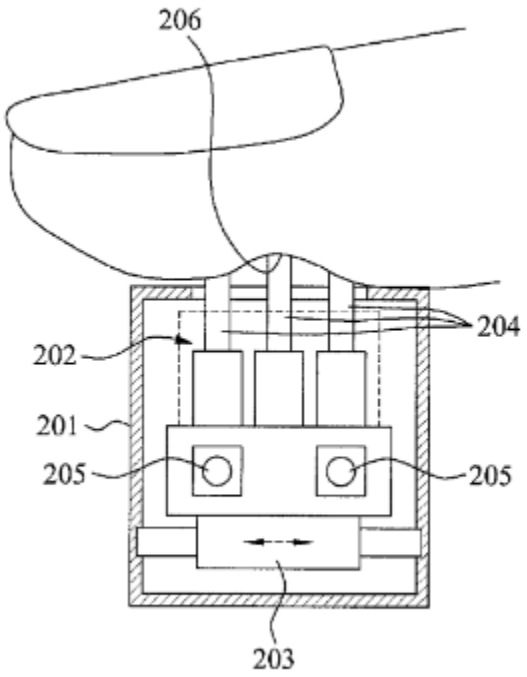



**Figure 2.3.1** 3DoF Tactile

<Patent Analysis>

This patent describes that this system uses actuators to control the movement. We need many resources of the last degree and we could have another idea which is that freedom is back and forth motion not rolling. In one aspect of one or more embodiments, the 3DOF (3DoF) tactile feedback device includes a moving unit capable of moving in at least one direction to contact a person's skin and an actuator moving the moving unit based on an input signal. The actuator may

feed back at least one of force applied to an object, motion, texture, and surface shape to the human skin by moving the movable part in a 3DOF direction. The 3DOF direction may include a horizontal direction, a vertical direction, and a front-back direction.

Inventor: Soo Chul Lim

Filing Date: Sep. 12, 2012

Publication Number: US2013/0088341 A1

**2.3.2 Patent #: 30-0975347**

Title: 3DoF Handheld Gimbal for Camera

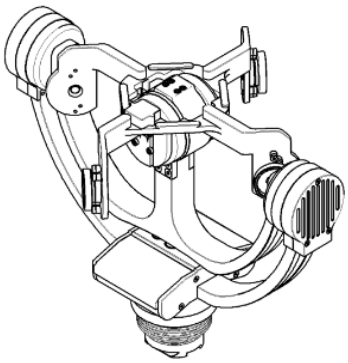


**Figure 2.3.2** 3DoF Handheld Gimbal for Camera Side View

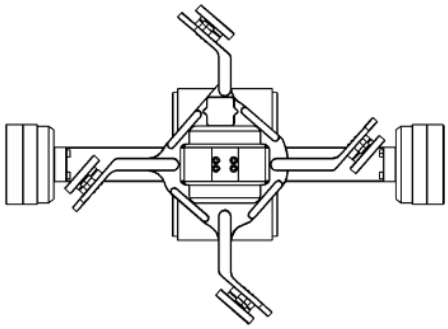


**Figure 2.3.3** 3DoF Handheld Gimbal for Camera Top View

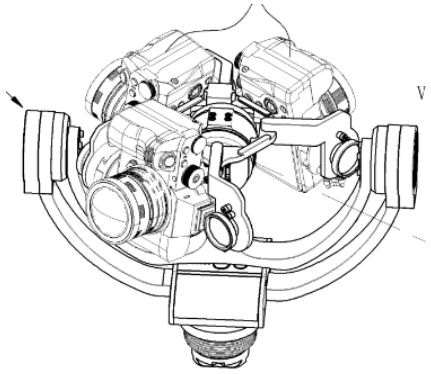


**Figure 2.3.4** 3DoF Handheld Gimbal and Camera

<Patent Analysis>

This patent describes a camera which is a 3DoF camera made for VR videos. It is a patent product that is very bulky and needs to be manually operated with three cameras installed. This design is designed to automatically adjust the vertical and horizontal state of the camera when taking a picture, to automatically correct the camera's rotation and shaking when taking a picture, to keep it in place, to ensure ease of operation and use. However, our project is going to install additional software that can track objects, and we're going to build a small, inexpensive 3DoF system.

Inventor: Choi Sung Gwon

Filing Date: Sep. 28, 2017

Publication Number: 30-2017-0045784

**2.3.3 Patent #: 20-2010-0012881**

Title: Camera module triaxial rotating bracket assembly of surveillance camera device

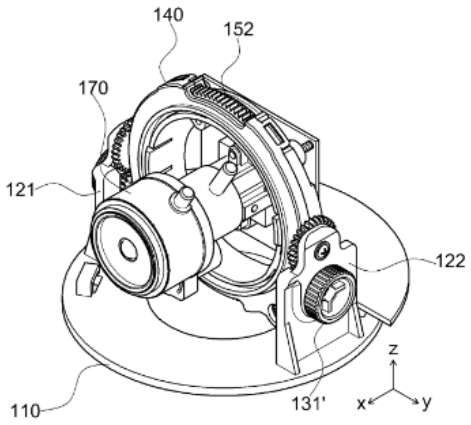



**Figure 2.3.5** Camera Module Triaxial Rotating Bracket Assembly of Surveillance Camera Device

<Patent Analysis>

This patent design describes that the camera module three-axis rotating bracket assembly of a surveillance camera device, a base rotatably provided with respect to the Z axis in the case body a pair of supports installed on the base; an axis adjusting knob that rotates on the Y axis At least one of the upper or lower sides has an exposure opening to expose a part of the outer circumferential surface of the X-axis rotor, one side is integrally fixed to the pivot gear, and the other side is rotatably installed on the other support, and the outer circumferential surface is exposed to the center of the pivot frame. The X-axis rotor with rim grooves; the locking projection formed on the outer peripheral surface is fixed to the locking groove to rotate in conjunction with the rotation of the X-axis rotor ; The rotating ring and the central through hole can be conveniently adjusted by the user.

Inventor: Jung Sung Ho

Filing Date: Dec. 28, 2010 Publication Number: 20-2010-0012881

**2.3.4 Patent #: 20-2010-0012881**

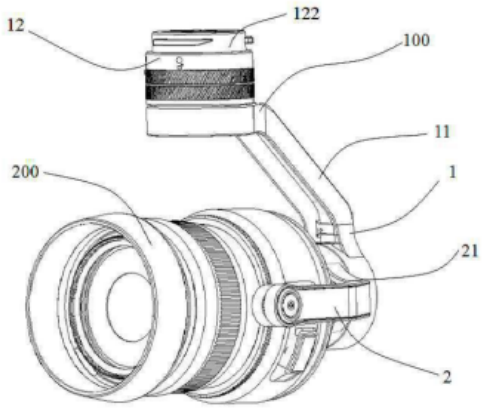



**Figure 2.3.6** 3DoF Gimbal Photographing Device

<Patent Analysis>

Title: 3DoF gimbal photographing device

This patent design describes three-axis gimbal and a three-axis gimbal photographing device, wherein the first hollow motor shaft of the three-axis gimbal includes a first hollow motor shaft, a first receiving chamber is installed in the first hollow motor shaft, and the second hollow motor shaft is accommodated in the pillar. The first conductive wire installed in the accommodating chamber is further included, the pitch shaft assembly further includes the second accommodating chamber and the second conductive wire installed in the pitch shaft arm accommodating chamber. However this is also a patent which is used manually.

Inventor: Osmo Technology

Filing Date: Dec. 03, 2020

Publication Number: 10-2010-0138837

**2.3.5 Patent #: 20-2010-0012881**

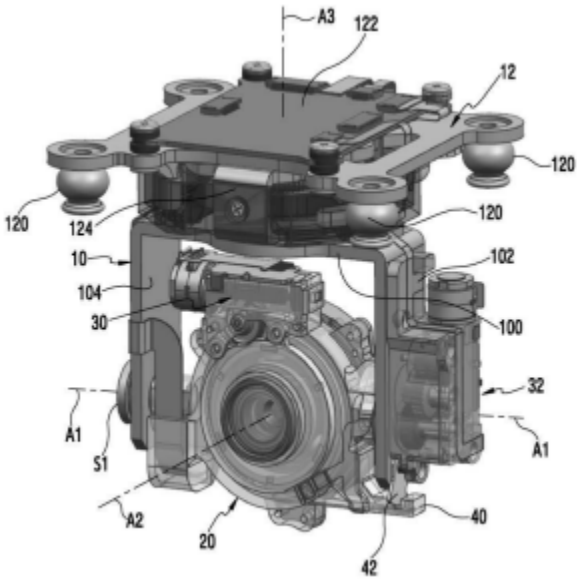



**Figure 2.3.7** 3DoF Adjustment Small Gimbal

<Patent Analysis>

Title:3DoF Adjustment Small Gimbal

This patent design describing a three-axis camera gimbal is disclosed in the present disclosure. The disclosed gimbal includes a first support; a lens barrel that includes a lens group and is rotatably coupled to the first support around the first axis A rolling drive unit mounted at the first position of the lens barrel, which provides a force to rotate the lens group around a second axis perpendicular to the first axis, a pitching drive unit mounted on the first support, and a second support rotatably coupled to the first and second axes, and a third support. Various embodiments of the present disclosure are possible.

Inventor: Kang Yoon Seok

Filing Date: May. 11, 2017

Publication Number: 10-2017-0050924

**2.3.6 Patent #: 10-2018-0060634**

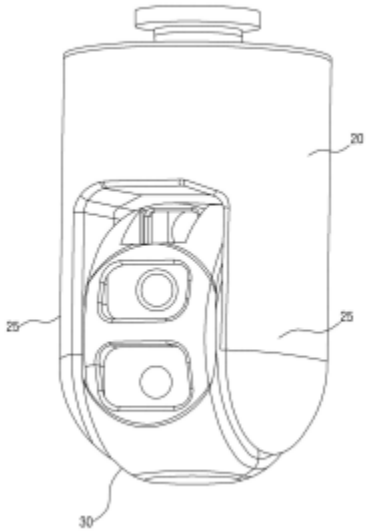



**Figure 2.3.8** Dome Type 3-Axis Gimbal

<Patent Analysis>

Title: Dome Type 3-Axis Gimbal

This design describes a three-axis gimbal, a first bracket fixed to one side of the outer surface of the first housing, a second bracket rotatably supported by the first bracket, and a roll rotation shaft rotatably supported inside the second bracket, including a roll rotation and a small rotation force.

Inventor: Kim Sung Jin

Filing Date: Nov. 29, 2016

Publication Number: 10-2018-0060634

**2.3.7 Patent #: 10-2016-0114296**

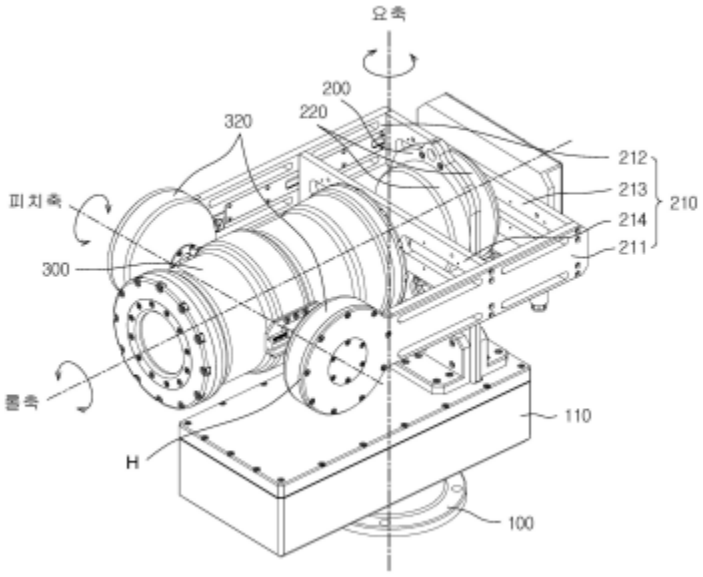



**Figure 2.3.9** 3DoF Gimbal

<Patent Analysis>

TItle: 3DoF Gimbal

The present invention provides a pair of BLDC motors in a three-axis gimbal to facilitate rotation around a yaw axis and a roll axis. At this time, in order to overcome the phase difference between each BLDC motor and match it, a clearance is formed at the coupling part.

Inventor: Won Young dae

Filing Date: Nov. 28, 2017

Publication Number: 10-2016-0114296

**2.3.8 Patent #: 10-2015-0173939**

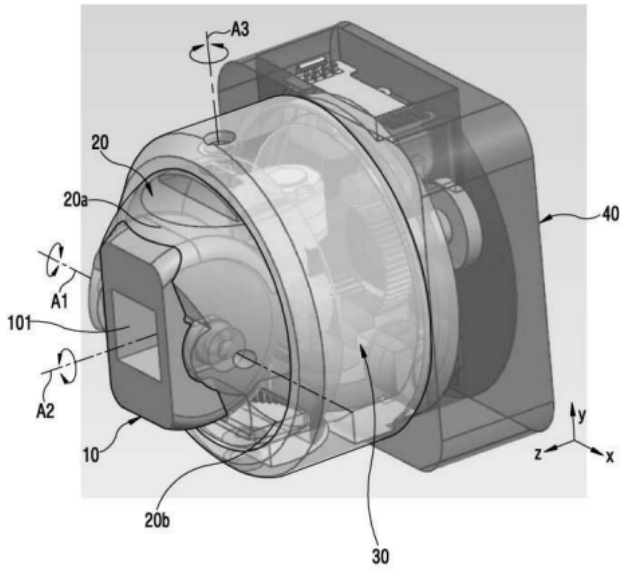



**Figure 2.3.10** Small Camera Gimbals and Electronic Devices With Them

<Patent Analysis>

Title: Small camera gimbals and electronic devices with them

This design is a camera gimbal which is disclosed in the present disclosure. The disclosed gimbal is a pitching housing with a lens part arranged in the camera gimbal, which rotates around the first axis, rotates around the second axis perpendicular to the first axis, and rotates around the third axis, and rotates around the third axis. Various embodiments of the present disclosure are possible.

Inventor: Kang Yoon Seok

Filing Date: Dec. 9, 2015

Publication Number: 10-2015-0173939

### 2.3.9 Patent #: 10-2015-0173939

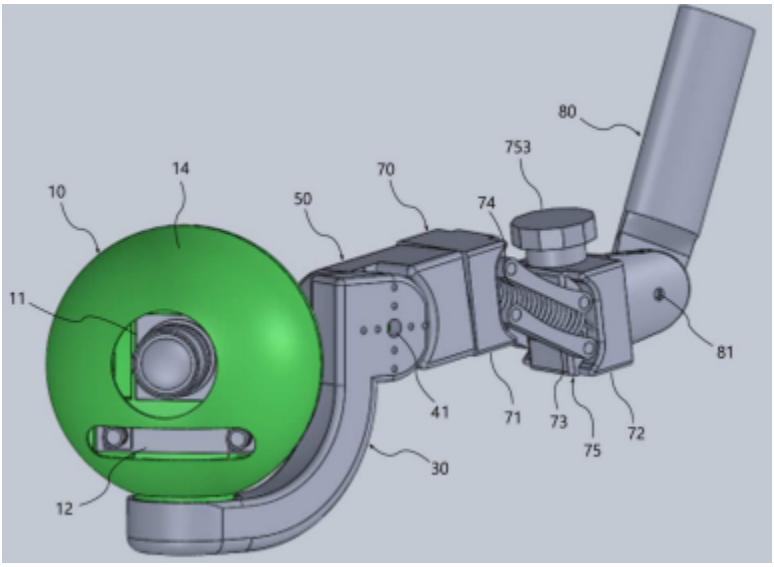



**Figure 2.3.11** Multiaxial Gimbal

<Patent Analysis>

Title: Multiaxial Gimbal

This invention is about a multi-axis gimbal that diversifies the operating range of precision detection devices, such as cameras, mitigates the impact generated while moving and adjusts the buffer rate to the weight of detection devices. A first axis motor is installed at one end of the first supporter. A second axis motor is installed at one end includes a third supporter configured with a spring installed to buffer movement between the group and the group

Inventor: Lee Sung Won

Filing Date: July. 1, 2019

Publication Number: 10-2019-0078813

**2.3.10 Patent #: 10-2015-0173939**

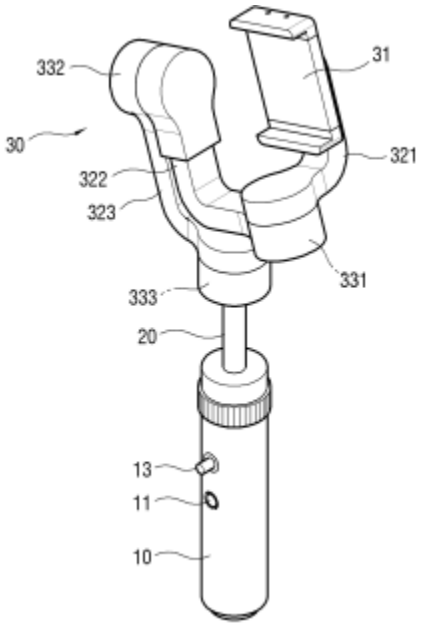



**Figure 2.3.12** Gimbal Device For Portable Terminal

<Patent Analysis>

Title: Gimbal Device For Portable Terminal

This invention is about a gimbal device, especially a handle part; A gimbal part supported by the tip of the handle part; A mount part on which a portable terminal equipped with a camera is mounted; A first shaft, a roll, and a third shaft provided between the handle part and the mount part to rotate in pitch, roll, yaw directions, respectively A control unit for controlling the first motor, the second motor, and the third motor is included.

Inventor: Kim Sung Hee

Filing Date: Mar. 8, 2022

Publication Number: 10-2022-0027572

## 2.4 Patent Summary

Most of the patents we found above were products that were not available to the general public because the DoF method we pursued was different and the volume was very large and long. There were problems with the weight that could be mounted on products such as drones, but could not bear the weight. In addition, the way the camera works is a manual camera that needs to be adjusted by a person and cannot be automatically tracked. That's why our group created the 3DoF design in the way we pursue and made products that reduce volume and weight. By adding additional software, we were able to automatically create products that we wanted to track. In this way, we made a difference from the products that are currently available.

## 2.5 Consumer Survey

Most of the existing cameras are made of 2DoF, and even if they are made of 3DoF, the volume and weight are not available to the general public. Cameras used in the movie industry are also bulky, but the price they sell is very high. However, the market for making videos through video platforms such as YouTube is growing. Through this platform, people who make videos are on a limited budget and cannot use expensive equipment. The production of miniaturized, lightweight, and low-cost 3DoF tracking cameras is expected to consume a lot of people who want to create high-level images like movies but can't.

As it is shown above, we expect consumption to increase in markets that use regular 2DoF cameras. Most of the space, defense, and video industries use 2DoF cameras. In these industries, the last degree of freedom is being adjusted through software. As a result, the volume is bound to increase and weight reduction is not possible. We expect to be able to mechanically

process what was done through software, produce higher-quality images, and lower costs in the space and defense industries.

# Chapter 3. **Product Design Specifications**

## 3.1 Executive Summary

### 3.1.1 Project Overview

The core purpose of this design is to design a lightweight axial mechanical gimbal system. Many conventional methods limit the axial design to the axis and away from the correction and object tracking of the other axis through data processing. The goal of this system is to prove its effectiveness by attaching it to a moving system or by fixing it to an external system.

### 3.1.2 Project Scope

This particular design can be applied to small unmanned vehicles, such as small unmanned vehicle drones, which have difficulty in stopping at fixed positions due to external force caused by airflow or external force generated by drone wings. Instead of fixing the position of the unmanned vehicle itself, the camera can fix the shape or color of the target regardless of the unmanned vehicle.

Moreover, this design can be applied to many cameras used on decks of ships and battleships to detect or closely track targets. Usually, ship decks use mechanical 2-3 axis gimbals for wave or disturbance or ship anchorage, but these gimbals are very heavy and expensive and are very low in general use for special vessels.

For a case where satellites orbiting the Earth in space are not gravity-free, so they have a very precise telescope-like system that holds images of target points in one location of the Earth and can be used for continuous positioning or monitoring, this design would be also suitable.

## 3.2 Product Service / Description

### 3.2.1 Project Context

Our design has been designed to minimize software processing in mechanical gimbals, so it can be manufactured in a small size, which eventually leads to cost savings and can be purchased at a low price and by installing microprocessors and batteries, it's made unmanned, and it's expanded its stability and coverage by safely operating the design without the user operating it directly in extreme environments

### 3.2.2 Product Characteristics

By installing microprocessors and batteries, the design has been made unmanned, extending stability and coverage by safely manipulating the design without the user's own manipulation in extreme environments. That's why it can be used in space exploration or in war to attach it to a tank or drone to fix the target.

### 3.2.3 Product Principles

**Table 3.2.1** Servo Motor for Pixy Cam

| Category | Specifications |
|---|---|
| Operating Voltage | 4.8V ~ 7.4V |
| Speed | 0.18 sec/60deg (4.8V) / 0.16sec/60deg (6V) |
| Torque | 17.8kg·cm (4.8V) / 21.5kg·cm (6V) |
| Size | 40mm×20mm×38.5mm (length×width×height) |
| Weight | 56g |
| Motor | 3 Pole Core motor |

| | |
|---|---|
| Gear Train | Metal (copper gear) |
| Ball Bearing | 2BB |
| Dead Band Width | 2usc |
| Interface | JR |
| Wire Length | 30cm |
| Type | Digital, 2BB, metal gear |

**Table 3.2.2** Servo Motor for Raspberry pi

| | |
|---|---|
| Modulation | Analog |
| Torque | 9.40 kg·cm (4.8V) / 11.0 kg·cm (6.0V) |
| Speed | 0.17 sec/60deg (4.8V) / 0.14 sec/60deg (6.0V) |
| Weight | 55.0 g |
| Dimensions | 40.6mm×19.8mm×42.9mm (length×width×height) |
| Motor Type | Coreless |
| Gear Type | Metal |
| Rotation / Support | Dual Bearings |

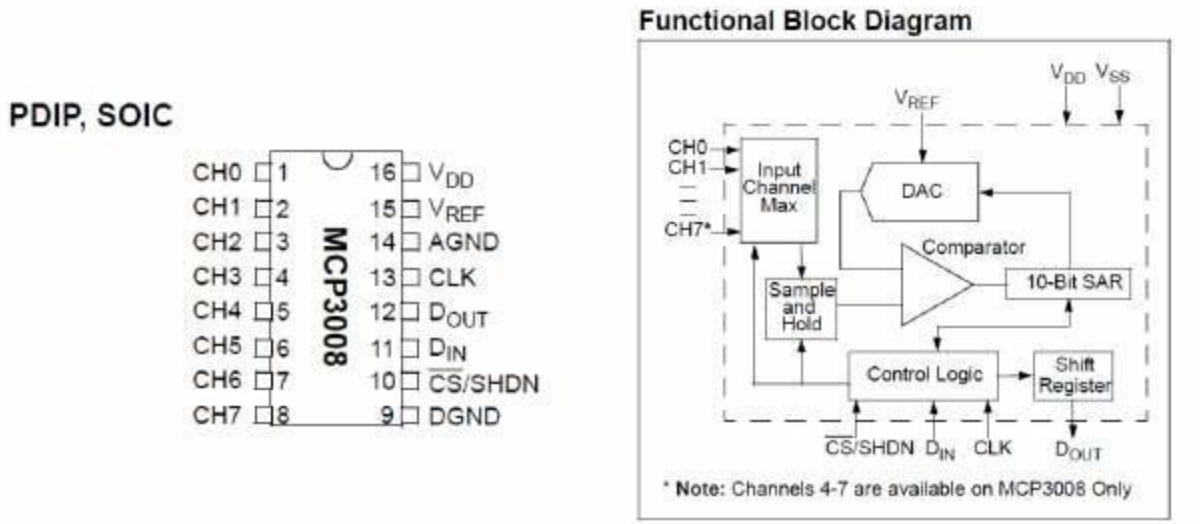



**Figure 3.2.3** Block Diagram for Analog Joystick

## 3.2.4 Major Functions and Use Cases

The design features customizable algorithms that allow you to recognize specific colors or recognize specific objects or shapes, so that you can track set values quickly and accurately. Instead of using a DC motor or a Stepper motor, a Servo motor was used to make it work smoothly, as well as to allow a certain level of torque to be maintained, which made it advantageous to operate at high speeds.

To test the performance of the biaxial mechanical gimbal before moving to the 3 DoF mechanical gimbal, a laser pointer was installed instead of the pan, tilt and the other axis, making it easy for spectators to see exactly what kind of object the design tracks when it moves.

The design can be used in diverse applications such as ships, traps, satellite systems, small unmanned vehicles, tanks or drones.

Many cameras are used on the deck of ships and battleships to detect or closely track targets. Usually, the deck of a ship uses a mechanical 2-axis gimbal to compensate for fluctuations by waves or disturbances, or for ship anchorage, but these gimbals are very heavy, expensive, and are only used in special vessels, making them very less versatile. This can be made lightweight and miniaturized, and can be widely used for more general ships and fishing boats.

In the market there are cameras which exist in satellites, but they are not a 3DoF system. However, the 3DOF System would be effective in space. In space, satellites orbiting around the Earth are not gravity-free, so they have a lasting force of motion even by very fine forces or disturbances. There is a very precise telescope-like system in the satellite, which can be used for continuous location tracking or target monitoring by locking the image of a target point at a location on Earth. This 3-axis gimbal is expected to be used in real-time and continuous fine tracking regardless of the movement, rotation, and movement of the mother ship satellite system.

Small unmanned vehicles such as drones are very difficult to hover in a fixed position during flight due to external forces caused by air currents or external forces generated by lift from drone wings. To overcome this, instead of fixing the position of the aircraft to stop flight, a system can be considered in which the unmanned vehicle itself moves, but the camera of the vehicle locks the shape or color of the target point and tracks it regardless of the unmanned vehicle's movement. By utilizing this, it can be used for fire drones that are expected to have severe external forces.

### 3.2.5 Constraints

Since the resolution of the camera is too low for the software to accurately recognize the object, it is necessary to simply use a camera with high resolution to solve this problem. However, most high-resolution cameras are USB A-type, so our system using Arduino is not suitable, so we can solve the problem by converting the microprocessor into a Raspberry Pi and configuring it as an HD-quality webcam.

In order to solve the wire tangling problem, the first iteration of pulling the wires out is applied by making a hole in the center of the design so that the wires are not connected out, but connected inwards so that they do not twist even after 360 degrees of rotation.

# Chapter 4. **Concept Design**

## 4.1 Overview

In this chapter, we will introduce the concept of the design and how each degree of freedom will rotate theoretically.

## 4.2 Concept Generation

### 4.2.1 Concept Design 1

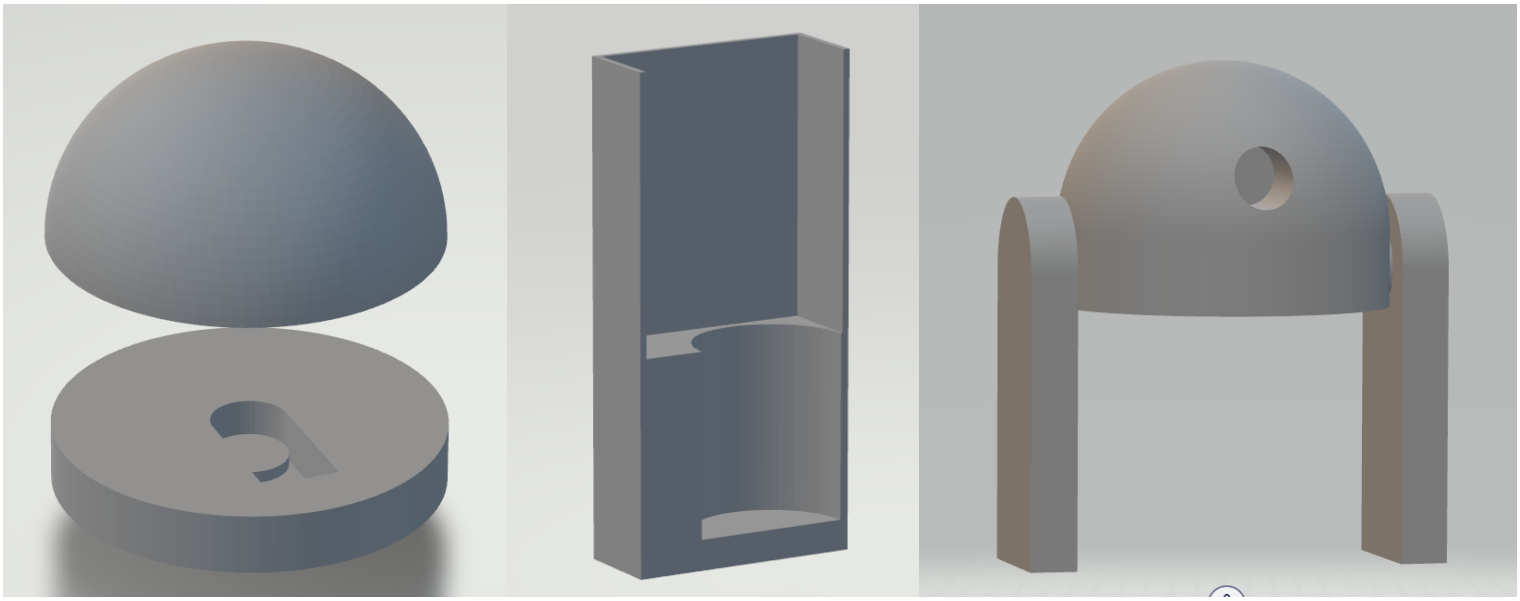


**Figure 4.2.1** Concept Design 1

## 4.2.2 Concept Design 2

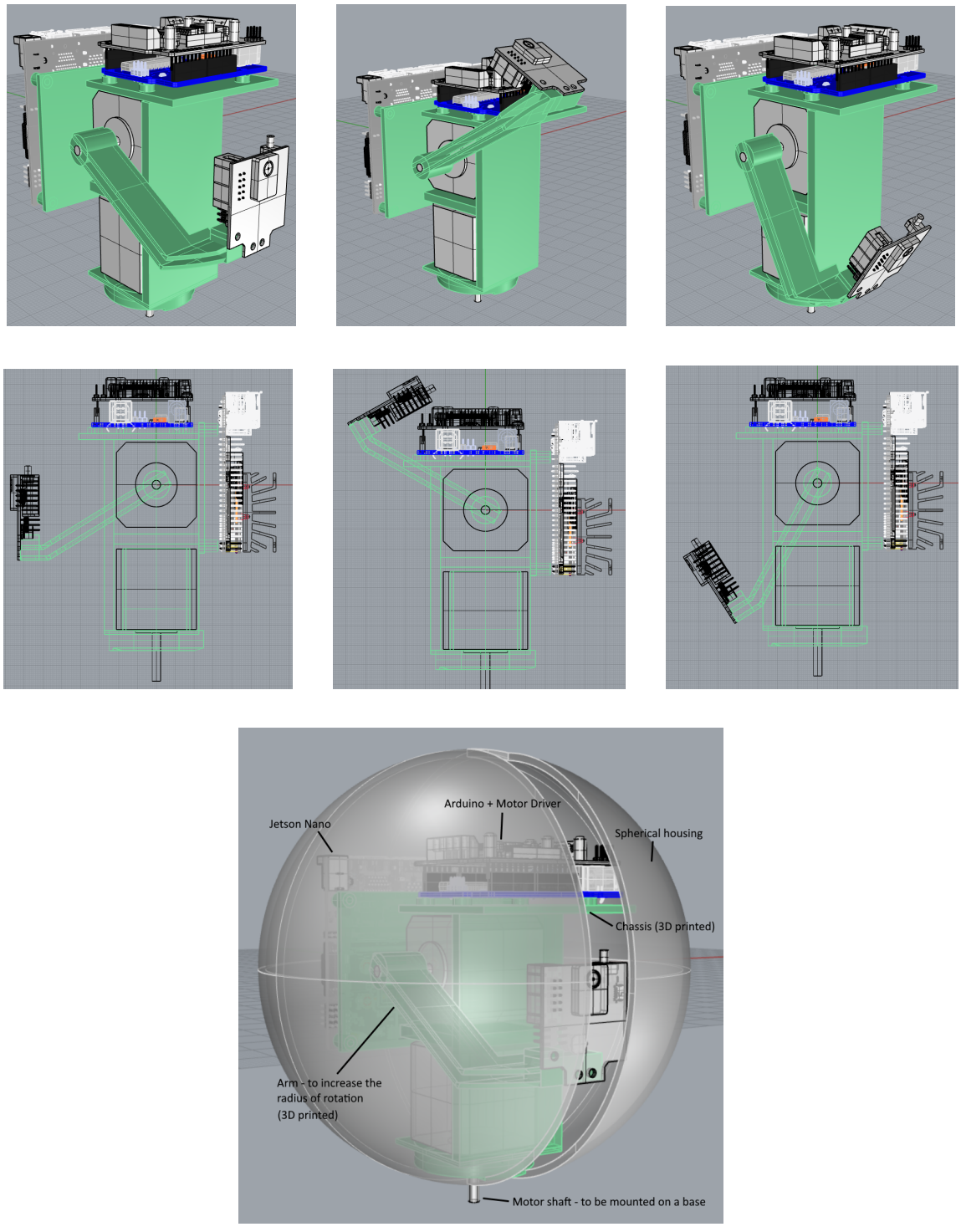



**Figure 4.2.2** Concept Design 2

### 4.2.3 Concept Design 3

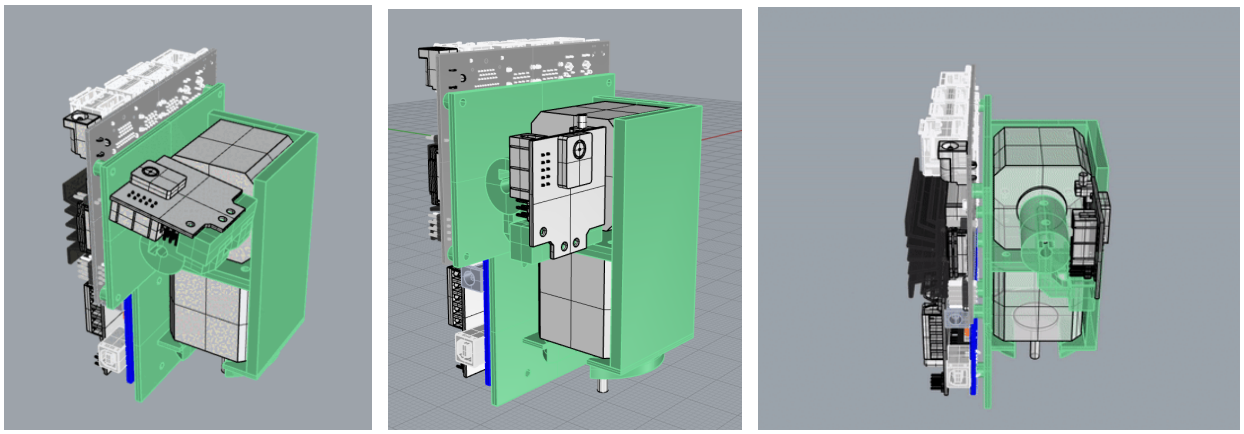


**Figure 4.2.3** Concept Design 3

## 4.3 Concept Evaluation

The first design was inspired by the shape of the R2B2 in Star Wars and conceived of a three-axis mechanical gimbal of the Android model. However, the problem with this design is that once the size grows, the weight increases significantly, and that it is not a design that can be made at a low price, which is the purpose of our final design. In addition, the design consists of several parts in arranging the wires connecting the motor and the microprocessorAs a result, there were difficulties in designing the wires to be smoothly connected without twisting them.

The problems of the first design were recognized and it was practically impossible to make a design, and the second design tried to design in a new direction, and inspired by CCTV, came up with a small dome-shaped design. The design came up with a small, low-cost design that can make efficient movements using small motors by making all parts centralized, minimizing Moment of Inertia, minimizing Torque, and moving with a small motor.

The second design is a little closer to our goal than the first, so we decided to make the second design the final design, but after thinking about any ways to improve the design more

efficiently, the microprocessor on the design was attached to the front so that when the design moves or rotates, there would be no obstruct which impedes the pan, tilt, and roll motion. Also, the length of the third axis was shortened so that the weight of the third axis gets reduced, and the range of motion gets reduced, resulting in a less powerful motor needed to make the design move and less materials needed to build the design. This will achieve our final goal that is building a 3 Dof mechanical gimbal that has a light weight and low cost.

## 4.4 Conclusion

The first step of building a design was started from an inspiration by R2B2 which comes from Star Wars, and the design kept being modified on and on which eventually became a dome shaped design. R2B2 design had three issues which were wire tangling, heavy weight, and huge size however, the final design reduced all three issues, and created a design that best fits our initial design purpose, and then continued to think about how to create an efficient design.

# Chapter 5. **Components of the Design**

## 5.1 Hardware

In order to check if the conceptual designs are appropriate, we needed physical experiments as well as theoretical analysis and calculations. The reason why we need the experiments is because we use programming language for our control system.

### 5.1.1 Servo Motor

A servo motor is a closed-loop mechanism that incorporates positional feedback in order to control the rotational or linear speed and position. The motor is controlled with an electric signal, either anlaog or digital, which determines the amout of movement which represents the final command position for the shaft.

In order to control a servo motor with few codes of programming, it is important to understand the mechanism of how a servo motor works, and its PWM system which stands for pulse width modulation.

PWM consists of square waves with the help of which we can control the up or high time. This is a digital way to control the digital signals that we use to vary the energy that is sent to a load or to encode information within the signal.

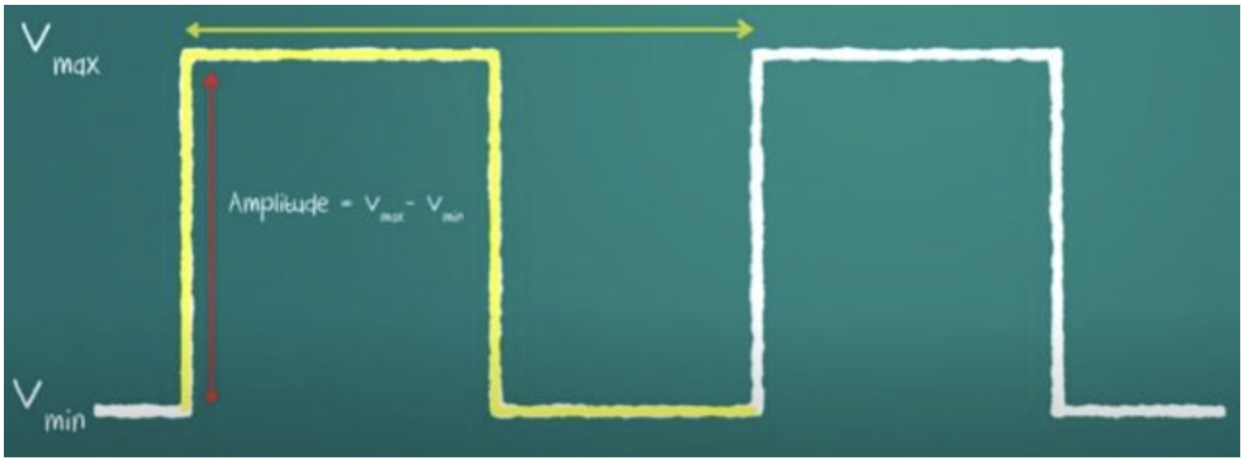



**Figure 5.1.1** PWM Signal

By using PWM signal maximum and minimum voltage values from the above figure, the wave oscillation can vary.

### 5.1.2 Arduino Nano

Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328P released in 2008. It offers the same connectivity and specs of the Arduino Uno board in a smaller form factor. The Arduino Nano is equipped with 30 male I/O headers, in a DIP-30-like configuration, which can be programmed using the Arduino Software integrated development environment, which is common to all Arduino boards and running both online and offline.

### 5.1.3 Pixy2 Cam

Pixy2 is the second version of Pixy. It's faster, smaller and more capable than the original Pixy, adding line tracking/following algorithms as well as other features. Pixy2 detects lines, intersections and small barcodes, intended for line-following robots. It has been improved

framerate to 60 frames per second and its tracking algorithms have been added to color-based object detection. Since our project was to construct a mechanical gimbal that tracks colored objects, we thought Pixie 2 was the most appropriate part, so we bought it and tested it, but unfortunately, due to its low resolution, we found that the recognition rate was not good.

### 5.1.4 HD Webcam

At first, Pixy Cam was constructed first to be equipped in the design with tracking software, but after several attempts, it was found that Pixy Cam's recognition rate was poor and changed its direction to using HD-quality webcam used in general computers. After switching to an HD webcam, the recognition rate improved exponentially compared to when using Pixy Cam, so it was able to get very satisfactory results

### 5.1.5 Portable Battery

Since the goal of the project was to devise a 3 DoF mechanical gimbal that autonomously tracks colored objects, the design needed to be designed to allow the design to move on its own without external control, and so it came up with attaching a portable battery to power it.

### 5.1.6 Laser Pointer

When testing a design, it's connected to a PC so that it can pinpoint what object it is looking at and where it's looking at, but the design has to be operated autonomously which means there would be no connection with PC to check whether it works appropriately or not. To resolve the issue, attaching a laser pointer has come up so that whoever watches how the design

operates can easily identify what the design is looking for and tracking at without checking it through the PC.

## 5.2 Control System

### 5.2.1 Block Diagram

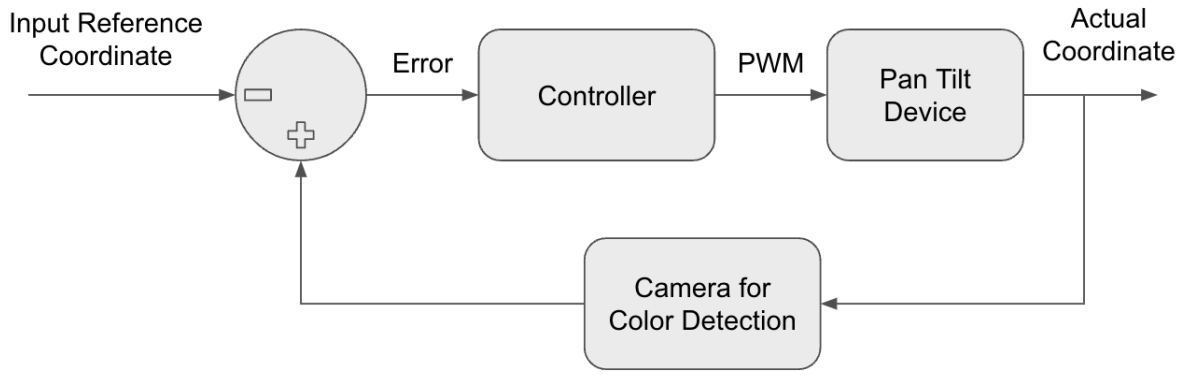



**Figure 5.2.1** Block Diagram for Control System

### 5.2.2 Programming

In order for our HD Webcam to track object, we needed to select the appropriate programming language to implement the object tracking algorithm. It turned out that Python has various packages like opencv which allows image recognition and pigpio which allows to use the gpio pins of raspberry pi board. Thus, we used Python to implement the color tracking algorithm along with the full controls of the servo motors. To simply explain our color tracking algorithm, the digital signal from usb camera detects a specific color in HSV code, which we typed in as an input. As a result, a bounding circle is drawn around the colored object. From this algorithm, we set the servo motor to follow the center point of the circle.

Using the similar mechanism, we added one more feature to our design, which is an analog joystick. Analog joystick sends out analog voltage signal which raspberry pi cannot read directly from the joystick. Thus, we used MCP3008 Analog-to-digital converter (ADC) in order to use the analog controller. The block diagram and the circuit diagram of the analog joystick are mentioned in section 3.2.3.

# Chapter 6. **Detailed Design & Prototype**

## 6.1 Project Design First Draft

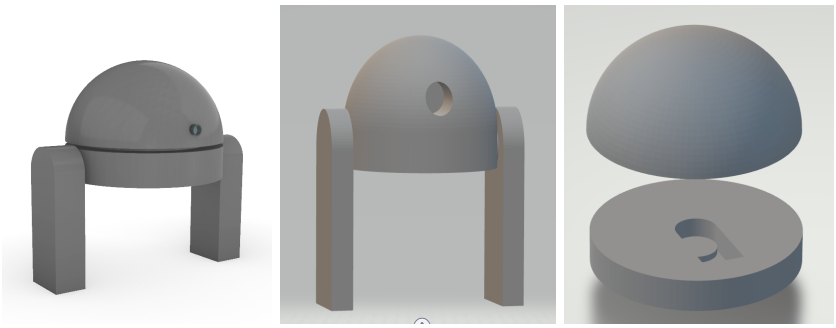
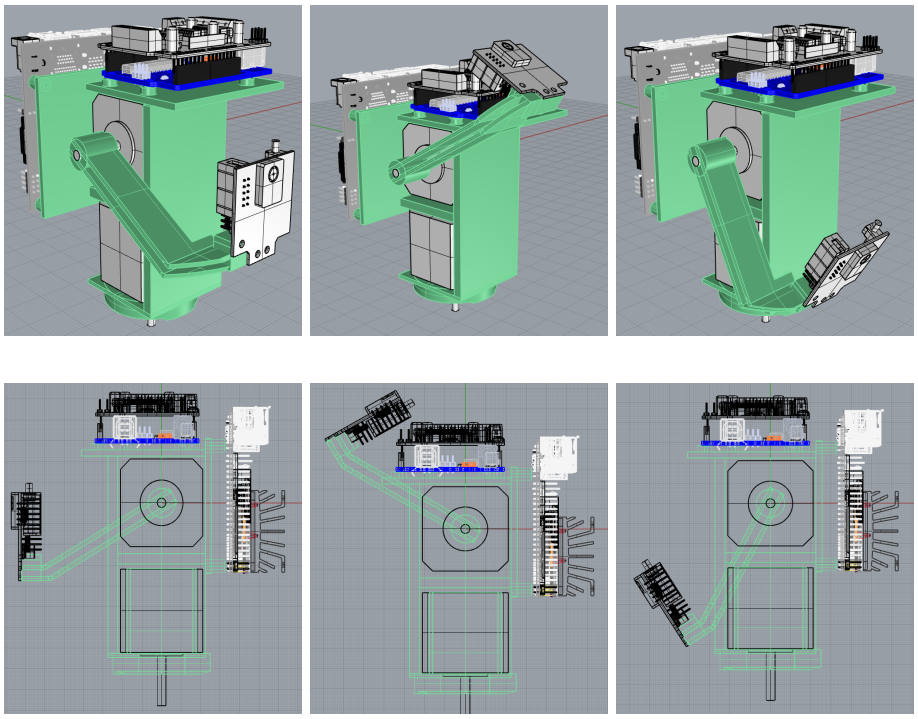




**Figure 6.1** First Design

The first design was made by referring to the shape of R2B2 in Star Wars. Like the R2B2 moving, the body on the leg moves up and down, the dome on the body moves left and right, and the camera part rotates on its own to create a rolling movement. However, the problem with this design is that it is bulky and heavy, so the design has been decided to be modified

## 6.2 Project Design Second Trial



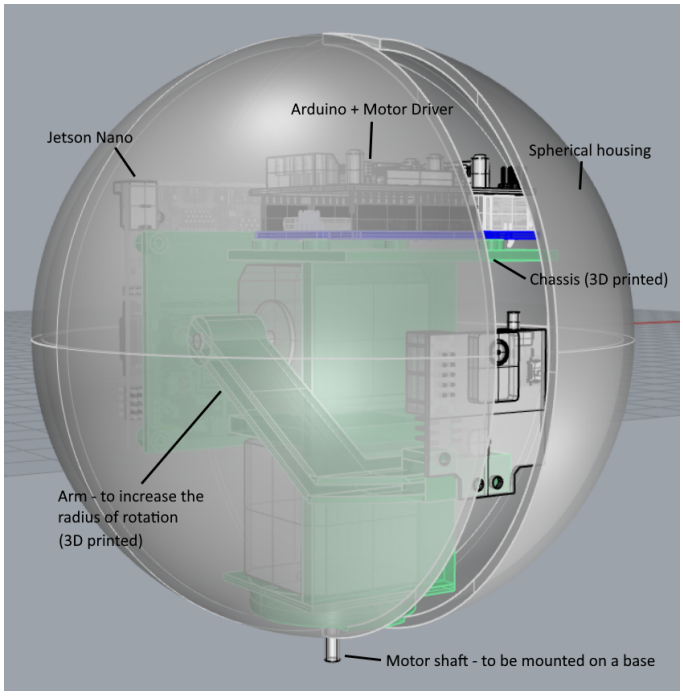



**Figure 6.2** Second Design

The second design was composed with a more developed version of the first design. The second design was designed to reduce the size by placing the parts in the middle and reducing the torque by bringing all the parts together in the middle, which eventually made the motor of less specification available and eventually reduced the weight of the design.

## 6.3 Final Design

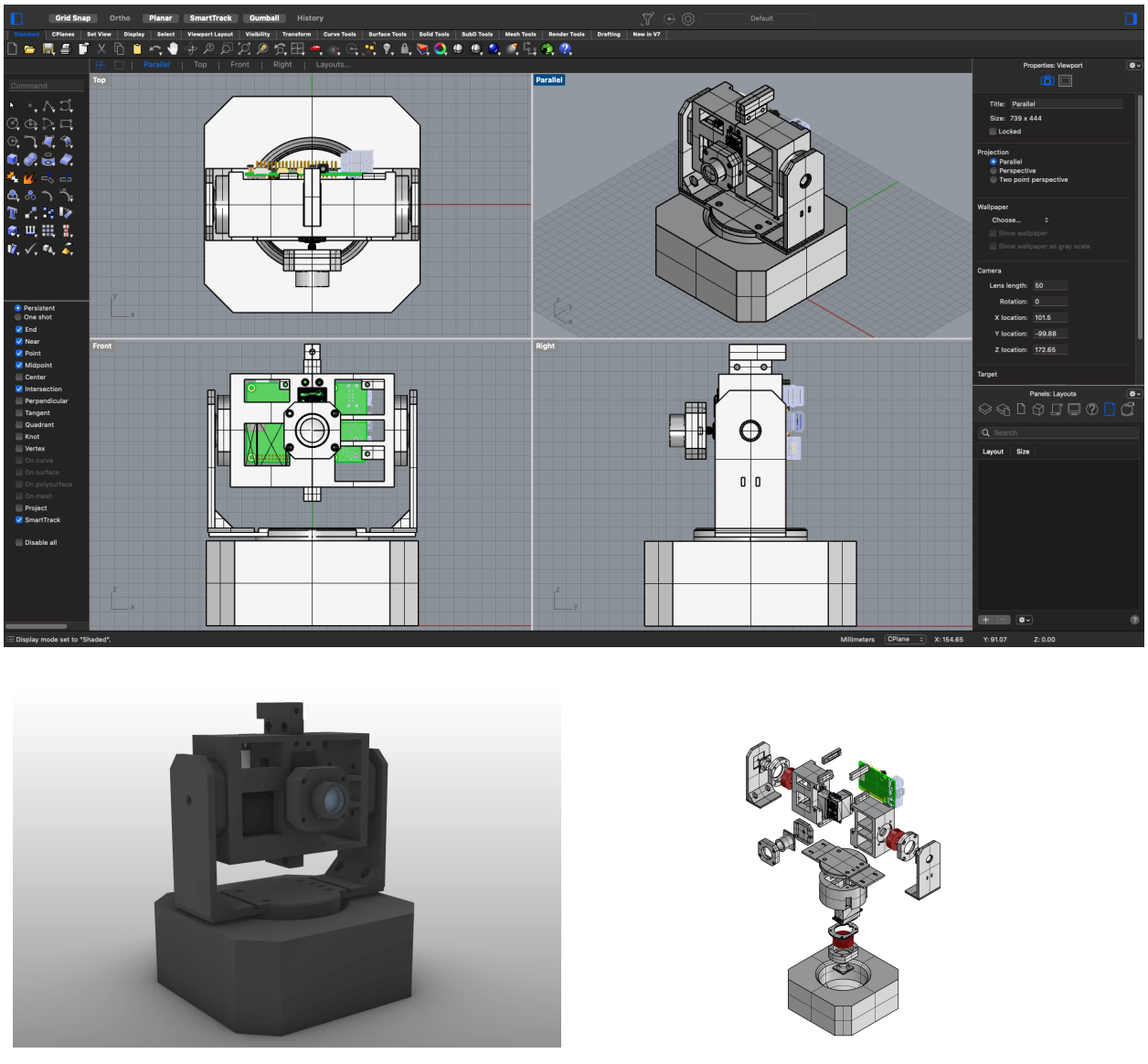



**Figure 6.3** Final Design

The second design was not satisfied with our design criteria so we have continuously thought about more efficient and effective design until the end. Finally, it was possible for us to come up with a design like CCTV, and reduce the size and weight by placing the parts a little more efficiently than the second design.

## 6.4 Conclusion

From the first design to the last design, we tried to make a more efficient design by thinking and working with the team members, and through continuous team meetings, we were able to share our opinions and give feedback to fill in the shortcomings.

We've always wondered where we can use the knowledge we've learned in school for four years, but when we actually designed and built our own design, we felt that four years of school learning was not wasted, and we felt the greatness of engineers who designed and built many equipment and systems in the field.

In addition, as we searched for various parts to make a successful design and looked for vendors, we learned that not only is it important to design the design, but also the right parts to support the design play a really important role. After searching for and comparing the parts needed for our design one by one, we went to the vendor and purchased them ourselves, and we were able to feel the greatness of the engineer once again.

# Chapter 7. **Personal Contribution**

We all essentially contribute equally and together to most parts of the project. However, there were some parts that we put individual efforts to initiate and then the whole team came and gave their ideas, and then started working on it together.

Hojung Lim

- Hojung Lim led a team meeting as a leader of Capstone Design Project, and helped manage the team schedule as well as planned to proceed with the schedule without being planned. Then, he performed a lot of coding, and continuously tried to create a perfect design. Whenever there was a need to purchase parts to make a design, he made an effort to contact the coordinator and get the parts delivered quickly.

Hakyeong Lee

- Hakyeong Lee contributed the most to 3D CAD modeling, produced many prototype CAD models, and actively accepted team members' feedback to continue to modify the design. Also, he searched and found various information such as the specifications of the parts required for the design, price, and place of purchase.

Junbin Choi

- Junbin Choi supported 3D CAD modeling in a way of playing the role of backup, constantly identified and performed the modeling mistakes through double-checking, and wrote many parts of the report, and each team meeting took notes of progress, deficiencies, or improvements to provide answers to the direction the team moves.

Yongeun Kim

- Yongeun Kim tried to find the best open source code for our design by searching and analyzing various codes in open cv, and when the CAD design was printed out to the 3D printer, it was necessary to manually remove the support to remove it, and in this regard, it was aggressive and quickly removed the support to help test the model quickly.

# Chapter 8. **Contract (Finance Support)**

**Table 8** Bill of Materials

| no. | Product | Quantity | Price(Won) |
|---|---|---|---|
| 1 | Battery | 1 | 29,900 |
| 2 | Surveilance Camera | 1 | 42,820 |
| 3 | Bolts and Nuts | 1 | 4,610 |
| 4 | Stepper Motors | 2 | 9,900 |
| 5 | Camera Module | 1 | 67,000 |
| 6 | DC motor | 1 | 18,890 |
| 7 | Arduino Nano | 1 | 27,000 |
| 8 | JDY-31 Bluetooth Module | 1 | 6,500 |
| 9 | A3144 Hall Effect Sensor | 3 | 2,800 |
| 10 | 2N3904 NPN Transistor | 1 | 60 |
| 11 | 3.0mm x 1.5mm ND magnet | 4 | 83 |
| 12 | 5.0mm x 1.5mm ND magnet | 2 | 90 |
| 13 | DRV8825 Stepping motor driver | 3 | 2700 |
| 14 | nema 56Step Steping Motor | 3 | 27,500 |
| 15 | Step Motor Driver SBD-12 | 3 | 39,600 |
| 16 | 4 Pin Socket Header | 3 | 90 |
| 17 | Servomotor | 1 | 6,500 |
| 18 | Servomotor | 3 | 14,000 |

| | | | |
|---|---|---|---|
| 19 | Arudino Nano | 2 | 29,000 |
| 20 | 9V Battery | 1 | 15,150 |
| 21 | 9V Battery Holder | 4 | 1,200 |
| 22 | AA Battery 20pc. | 1 | 12,900 |
| 23 | AA Battery Holder | 4 | 1,000 |
| 24 | Subbor Motor Kit | 1 | 25,300 |
| 25 | Bearing | 3 | 6690 |
| 26 | Electric Driver | 1 | 38,200 |
| 27 | Supplementary Battery | 3 | 39,900 |
| 28 | Multi-Charger | 3 | 103,050 |
| 29 | Arduino 6-axis gyro sensor | 1 | 15,400 |
| 30 | Paspberry Pi | 1 | 135,000 |
| 31 | Servomotor | 3 | 8,900 |
| 32 | Supplementary Battery | 1 | 14000 |
| 33 | Micro-HDMI | 1 | 14000 |
| 34 | 25mm 3M Screw | 1 | 15000 |
| 35 | 30mm 3M Screw | 1 | 15000 |

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# Appendix

## Appendix A. Python Code for Color-Tracking and Servo Motor Control

```
# MEC441 Team AITS Servo Motor Control with Color-Tracking Algorithm

import numpy as np

import time

import cv2

import pigpio

from numpy import interp

# when running pigpio, type in command:

# sudo pigpiod

# python pantilt_color.py

panServo = 23

tiltServo = 22

# default servo position

initPos = 1500

panPos = 1500

tiltPos = 1500

servo = pigpio.pi()

servo.set_servo_pulsewidth(panServo, initPos)

servo.set_servo_pulsewidth(tiltServo, initPos)

minMov = 1

maxMov = 5
```

```
def movePanTilt(cenX, cenY):
    global panPos
    global tiltPos
    if int(cenX) > 360:
        panPos = int(panPos - interp(int(cenX), (360, 640), (minMov, maxMov)))
    elif int(cenX) < 280:
        panPos = int(panPos + interp(int(cenX), (280, 0), (minMov, maxMov)))
    if int(cenY) > 280:
        tiltPos = int(tiltPos - interp(int(cenY), (280, 480), (minMov, maxMov)))
    elif int(cenY) < 200:
        tiltPos = int(tiltPos + interp(int(cenY), (200, 0), (minMov, maxMov)))
        if int(cenX) <= 360 and int(cenX) >= 280:
        panPos = initPos
    if int(cenY) <= 280 and int(cenY) >= 200:
        tiltPos = initPos
    if not panPos > 2500 and panPos < 500:
        servo.set_servo_pulsewidth(panServo, panPos)
    if not tiltPos > 2500 and tiltPos < 500:
        servo.set_servo_pulsewidth(tiltServo, tiltPos)



#Capture from external USB webcam instead of the in-built webcam (shitty quality)
cap = cv2.VideoCapture(0)
```

```
#kernel window for morphological operations
kernel = np.ones((5,5),np.uint8)
#resize the capture window to 640 x 480
ret = cap.set(3,640)
ret = cap.set(4,480)
#upper and lower limits for the color yellow in HSV color space
lower_specific = np.array([9, 60, 80])
upper_specific = np.array([24, 255, 255])
#begin capture
while(True):
    ret, frame = cap.read()
    #Smooth the frame
    frame = cv2.GaussianBlur(frame,(11,11),0)
    #Convert to HSV color space
    hsv = cv2.cvtColor(frame, cv2.COLOR_BGR2HSV)
    #Mask to extract just the yellow pixels
    mask = cv2.inRange(hsv,lower_specific, upper_specific)
    #morphological opening
    mask = cv2.erode(mask,kernel,iterations=2)
    mask = cv2.dilate(mask,kernel,iterations=2)

    #morphological closing
    mask = cv2.dilate(mask,kernel,iterations=2)
```

```
    mask = cv2.erode(mask,kernel,iterations=2)
    #Detect contours from the mask
    cnts = cv2.findContours(mask.copy(), cv2.RETR_EXTERNAL,
cv2.CHAIN_APPROX_SIMPLE)[-2]
    if(len(cnts) > 0):
        #Contour with greatest area
        c = max(cnts,key=cv2.contourArea)
        #Radius and center pixel coordinate of the largest contour
        ((x,y),radius) = cv2.minEnclosingCircle(c)
        movePanTilt(x, y)
        if radius > 5:
            #Draw an enclosing circle
            cv2.circle(frame,(int(x), int(y)), int(radius),(0, 255, 255), 2)
            #Draw a line from the center of the frame to the center of the contour
            cv2.line(frame,(320,240),(int(x), int(y)),(0, 0, 255), 1)
            #Reference line
            cv2.line(frame,(320,0),(320,480),(0,255,0),1)
            radius = int(radius)
            #distance of the 'x' coordinate from the center of the frame
            #width of frame is 640, hence 320
            length = 320-(int(x))

    else:
```

```
            servo.set_servo_pulsewidth(panServo, initPos)
            servo.set_servo_pulsewidth(tiltServo, initPos)

        #display the image
        cv2.imshow('frame',frame)
        #Quit if user presses 'q'
        if cv2.waitKey(30) & 0xFF == ord('q'):
            servo.set_servo_pulsewidth(panServo, 0)
            servo.set_servo_pulsewidth(tiltServo, 0)
            break

#Release the capture
cap.release()
cv2.destroyAllWindows()
```

## Appendix B. Python Code for Servo Motor Control with Analog Joystick

```
import spidev

import time

import os

from gpiozero import Servo

# servo pins

panServo = 23

tiltServo = 22

pan = Servo(panServo)

tilt = Servo(tiltServo)

pan.value = None

tilt.value = None

# Open SPI bus

spi = spidev.SpiDev()

spi.open(0,0)

spi.max_speed_hz = 1000000

# Function to read SPI data from MCP3008 chip

# Channel must be an integer 0-7

def ReadChannel(channel):

        adc = spi.xfer2([1, (8+channel) << 4, 0])

        data = ((adc[1] & 3) << 8) + adc[2]

        return data
```

```
# Define sensor channels
# (channels 3 to 7 unused)
swt_channel = 0
vrx_channel = 1
vry_channel = 2
# Define delay between readings (s)
delay = 0.5
# endless loop
while True:
        # Read the joystick position data
        vrx_pos = ReadChannel(vrx_channel)
        vry_pos = ReadChannel(vry_channel)
        # Read switch state
        swt_val = ReadChannel(swt_channel)
        # Print out results
        print("----------------------------------------")
        print("X : {} Y : {} Switch : {}".format(vrx_pos, vry_pos, swt_val))
        if vrx_pos >= 0 and vrx_pos < 512:
                print("pan: left")
                pan.value = 0.1
        elif vrx_pos >= 512 and vrx_pos < 540:
                print("pan: stop")
                pan.value = None
```

```
elif vrx_pos > 680:
        print("pan: right")
        pan.value = -0.5
if vry_pos >= 0 and vry_pos < 512:
        print("tilt: up")
        tilt.value = -0.5
elif vry_pos >= 512 and vry_pos < 540:
        print("tilt: stop")
        tilt.value = None
elif vry_pos > 680:
        print("tilt: down")
        tilt.value = 0.1

# Wait before repeating loop
time.sleep(delay)
```