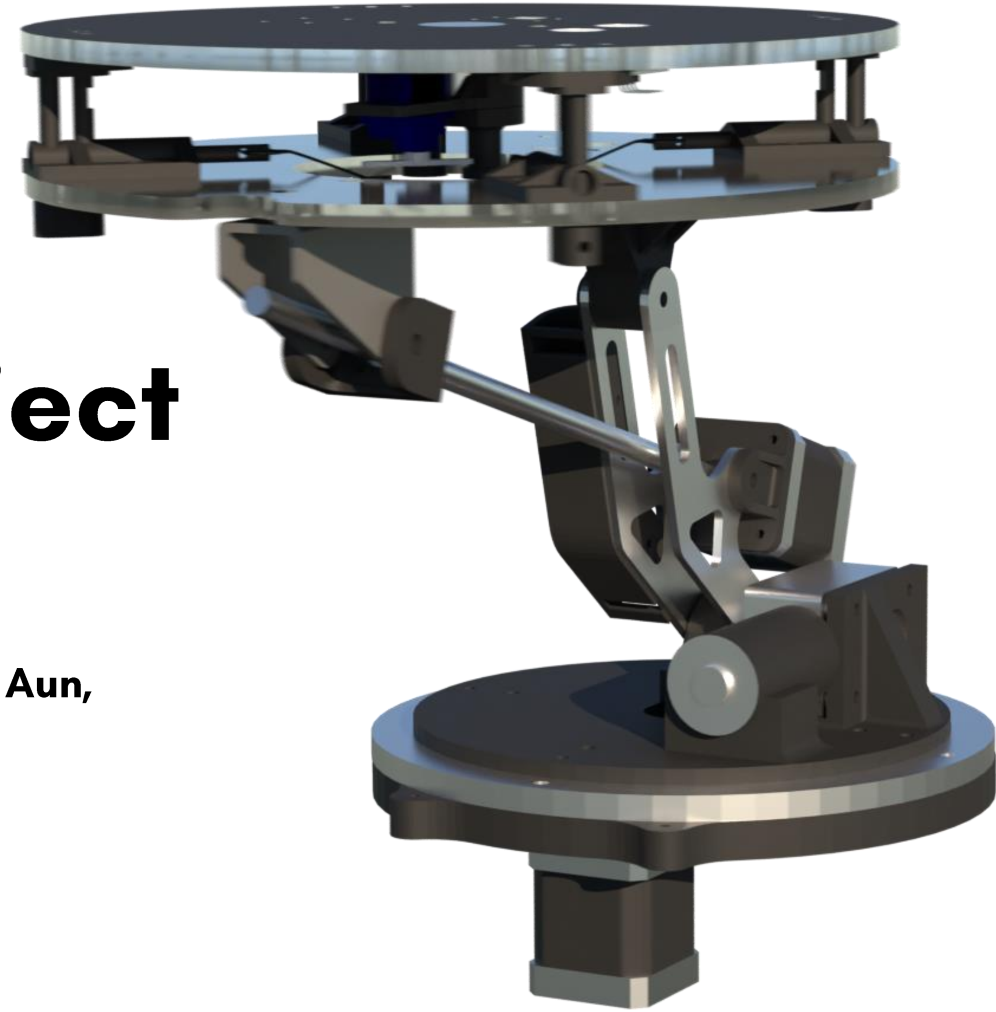
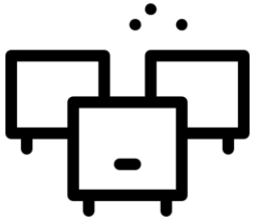
FEEG6013 Group Design Project



Group number	**49**
Project title	**Integration of drone and rover**
Member(s)	**Ung Shern Khai, Jalen Tan Khai Zhen, Toh Zheng Aun, Gai Zhe Wong, Ken Ooi Mo Herng**
Primary supervisor	**Dr Mohamed Torbati**
Secondary supervisor(s)	**Dr Mohammad Soorati, Dr Ayodeji Abioye**
Year	**2023 / 2024**

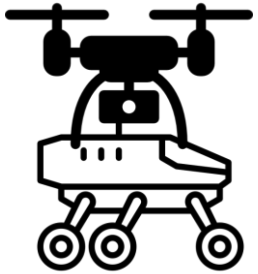
INTEGRATION OF DRONE & ROVER

IN COLLABORATION WITH ECS DEPARTMENT



SWARM ROBOTICS APPLICATIONS

A PROJECT THAT CAN BE FURTHER BUILT ON



LANDING PLATFORM FOR DRONE

EXISTING DRONE DOCKING STATIONS

Weight: 105kg. Unfolded Dimensions (L x W X H): 1675mm x 885mm x 735mm
DJI docking station

BIG IN SIZE

STATIONARY

REQUIRES FLAT PLATFORM

PROJECT AIMS & OBJECTIVES

PORTABLE

ACCOMMODATE ROUGH TERRAINS

SMALL

VERSATILE

PROJECT DEPARTMENTS

HARDWARE

1. Design, modelling & FEA analysis
2. Manufacturing of prototypes
3. Prototype assembly and testing

AVIONICS

1. Ground control station
2. Initial setup and calibration of drone

SOFTWARE

1. Drone Detection
2. Landing platform programming

ELECTRONICS

1. Ensure sufficient power for all components
2. Source necessary components within specification for project application

PROJECT REQUIREMENTS

HARDWARE

- Safely catch & hold a landing drone (on top of a rover)
- Accommodate moving platform, inclined surface
- Tolerate ±10cm offset from center during landing
- Withstand a load of > 2.5kg
- Flexible to accommodate a wide range of drones

AVIONICS

- Conduct flight test within indoor areas (GPS denied environment)
- Achieve stable flight throughout testing

PROJECT REQUIREMENTS

SOFTWARE

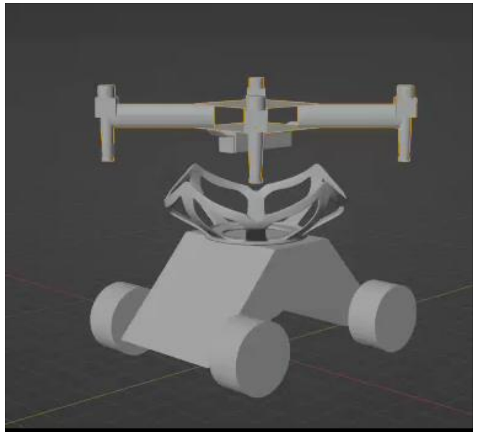
- Tracking system needs to have a response time < 100ms
- Have controllers to generate appropriate signals to actuators with the aid of sensor input as feedback

ELECTRONICS

- All electronic components needs to fit within the rover
- Components needs to be operational for 20 minutes

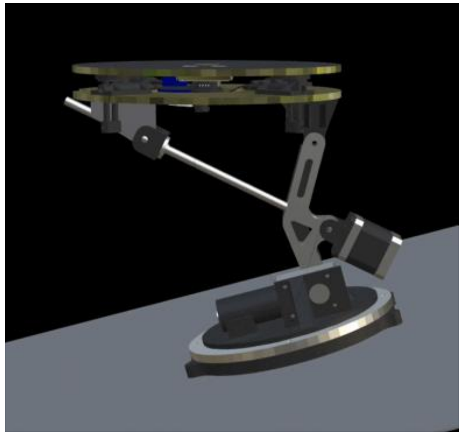
DRONE POSITIONING METHODS

PASSIVE



- No External Power Source Required
- Specific Geometry Required
- Gravity Dependent

ACTIVE



- Responds to uncertainty
- Involves electronic control system & actuators

DRONE POSITIONING METHODS

PASSIVE

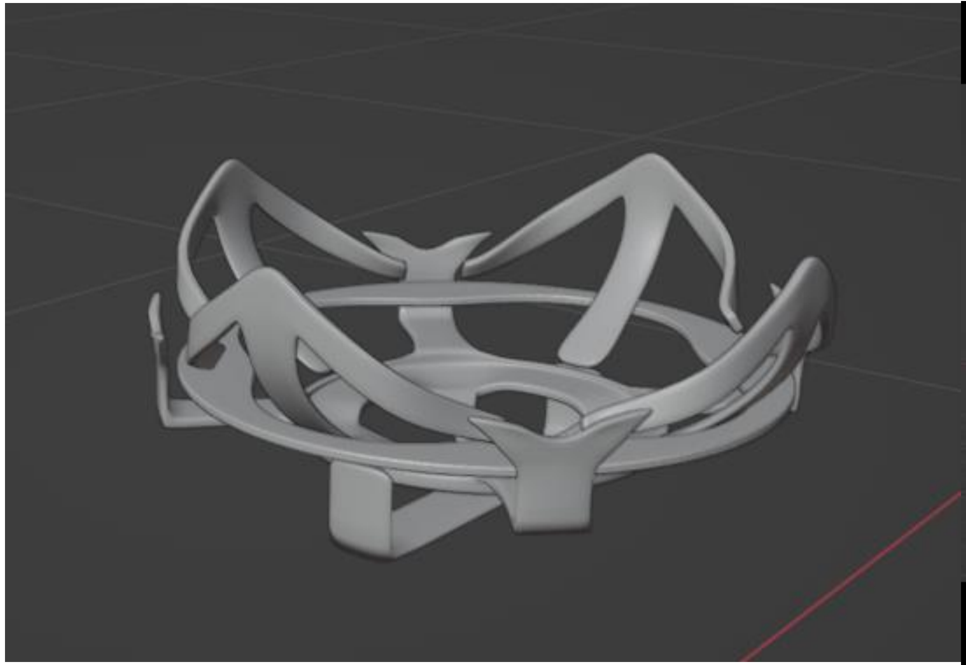
Pros	Cons
Simple implementation	Low tolerance to landing error
No external power required	Require a surface geometry that complements the UAV
No user input required	
Light and portable	

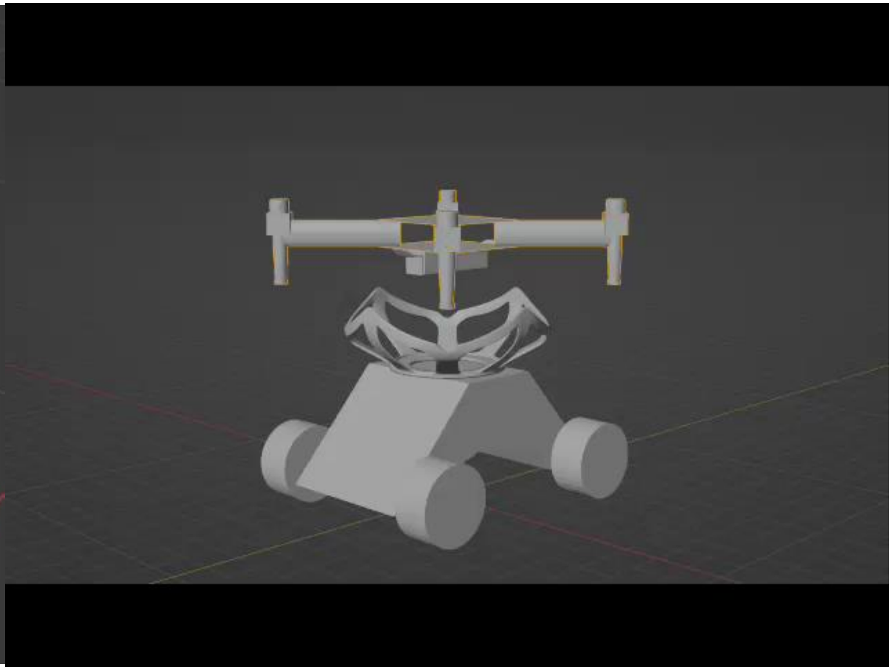
ACTIVE

Pros	Cons
Larger tolerance to landing error	Increased complexity in overall system
Responds to UAV movements in real-time	Higher cost
	Heavier and larger

DRONE POSITIONING METHODS

PASSIVE POSITIONING DESIGN

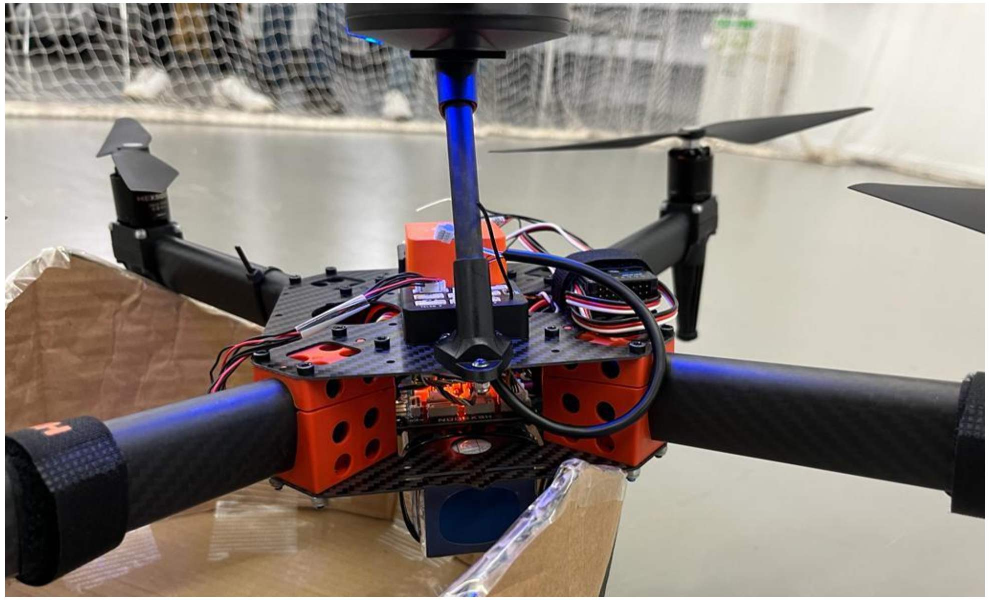




PASSIVE POSITIONING DESIGN TEST

PASSIVE POSITIONING TEST FINDINGS

- Low tolerance to landing error
- Design was not modular (specific drone size required)
- Requires specific landing orientation
- Risk of damaging drone blade due to elevated geometry



Passive positioning test result 1

Passive positioning test result 2

ACTIVE MECHANISM: DESIGN & APPROACH

INCLINATION

Allow for safe docking on rough terrains

LONGER REACH

Increase tolerance to landing error

MODULAR

A platform that could support different types / dimensions of drones

ACTIVE MECHANISM: DESIGN & APPROACH

INPUTS → **PROCESSING** → **OUTPUTS** → (back to INPUTS)

INPUTS

To detect the position of the drone
- Sensors
- Camera
- Others

PROCESSING

To process data:
- Fast
- Accurate
- Able to facilitate connections between inputs & outputs

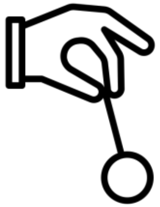
OUTPUTS

To move the platform to sensed position
- Motors
- Actuators

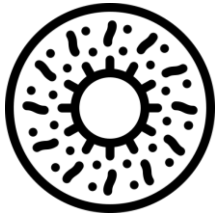
EARLY IDEAS

Funnel System

Magnets



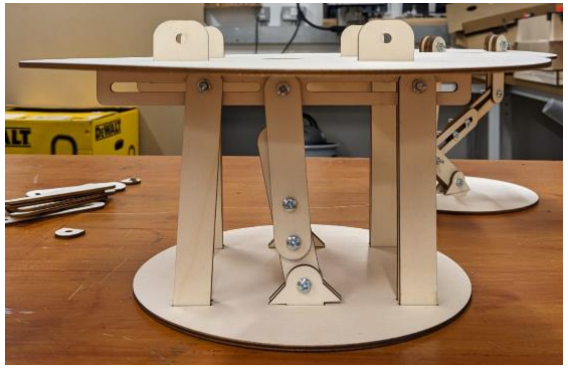
Guiding Ball



Iris Mechanism

EARLY PROTOTYPES

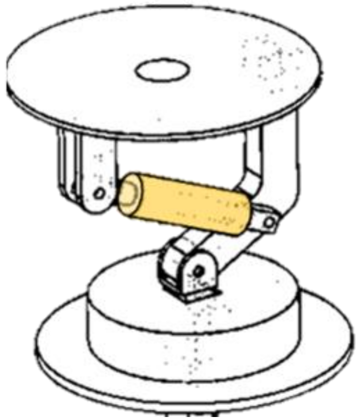
Single actuator arm system



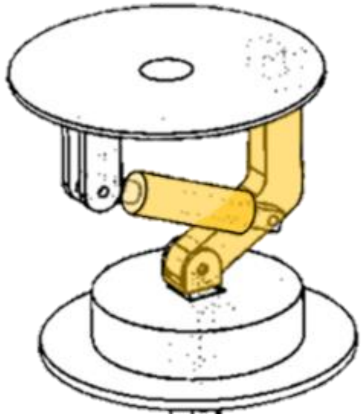
Dual actuator linkage system

Linkage system

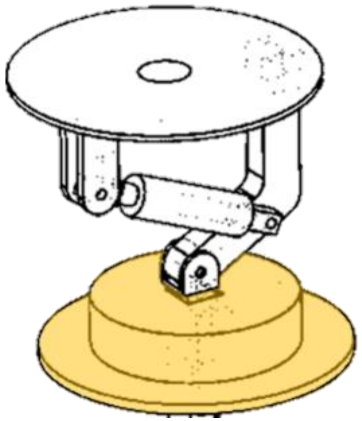
ACTIVE MECHANISM: DESIGN & APPROACH



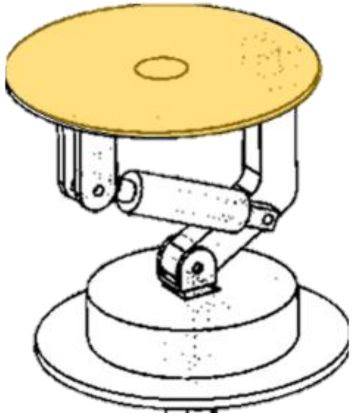
Surface levelling mechanism



Arm & Actuation



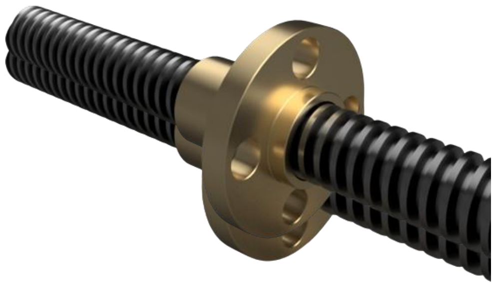
Platform Base



Top Platform

ACTIVE MECHANISM: DESIGN & APPROACH

SURFACE LEVELLING MECHANSIM



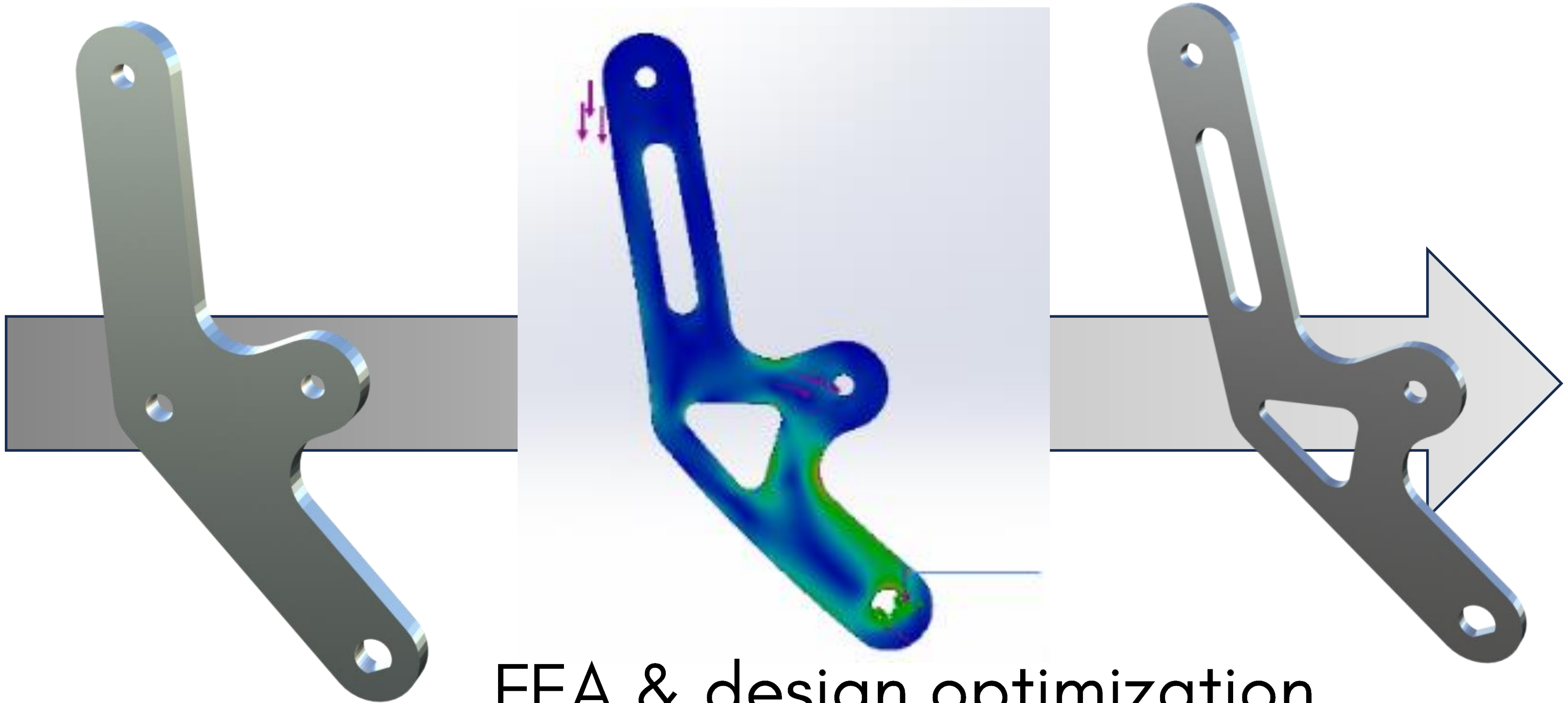
Lead Screw

- Faster
- Lighter
- Limited Torque

Linear Actuator

ACTIVE MECHANISM: DESIGN & APPROACH

ARM AND ACTUATION

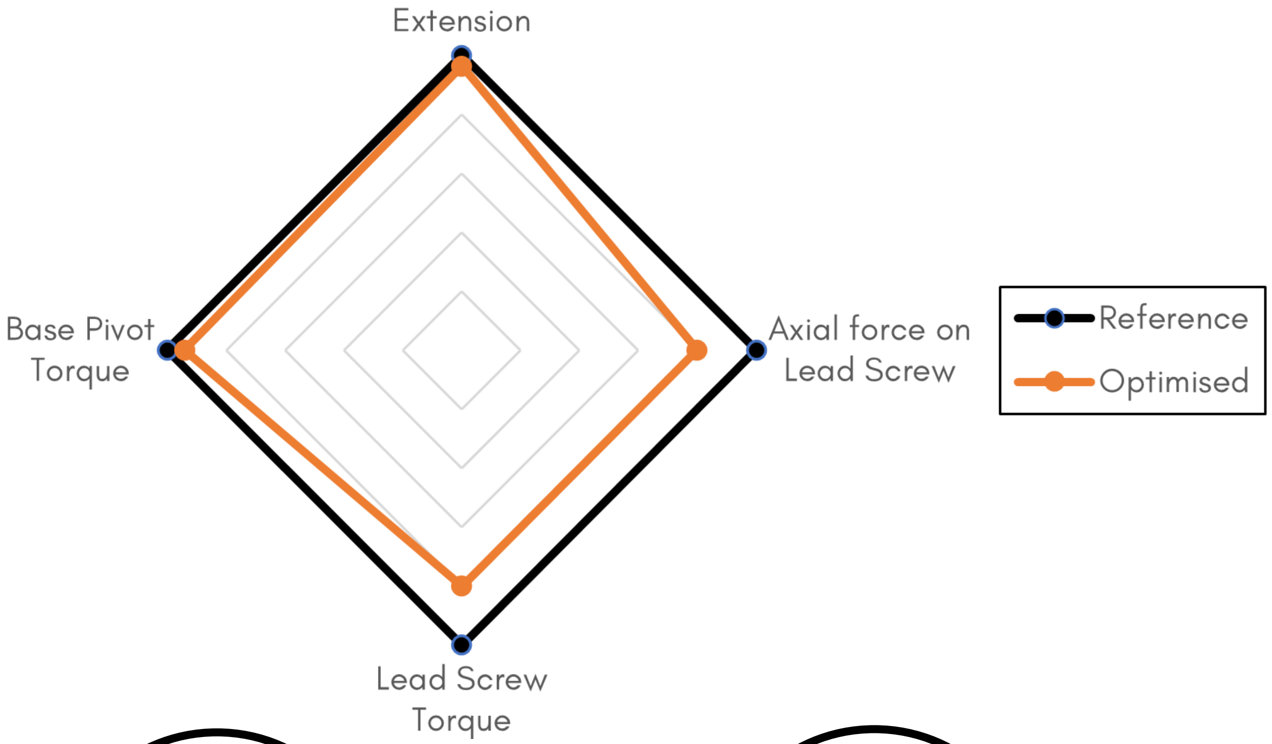


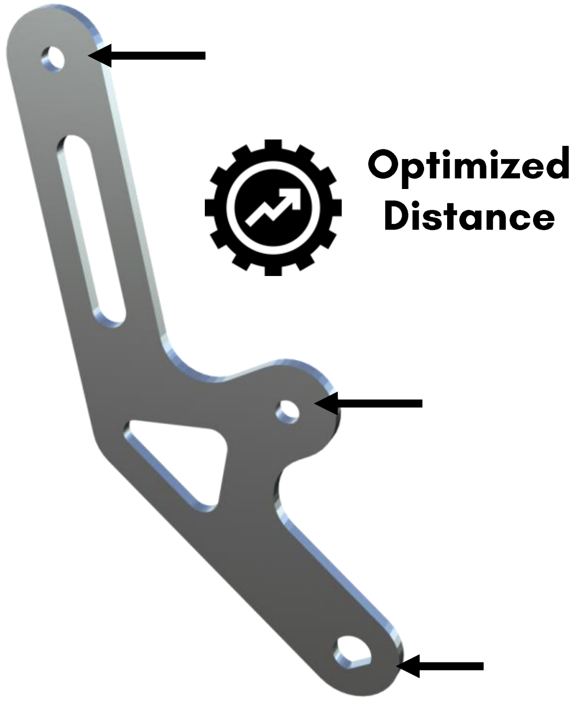
FEA & design optimization

58% REDUCED

Weight

ARM AND ACTUATION



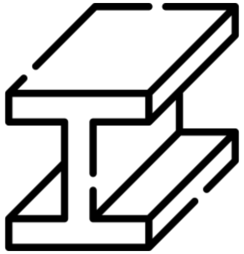


20%
LESS

Torque
on lead screw

20%
LESS

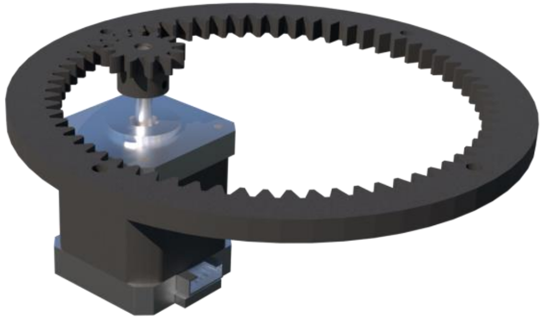
Axial Force
on lead screw



Stainless Steel

ACTIVE MECHANISM: DESIGN & APPROACH

PLATFORM BASE



Smooth Rotation

- Ring bearing sandwiched between base moving and fixed layers

Customized gear ratio

- 5.5:1 gear ratio
- Output of 0.5 revolutions per second

ACTIVE MECHANISM: DESIGN & APPROACH

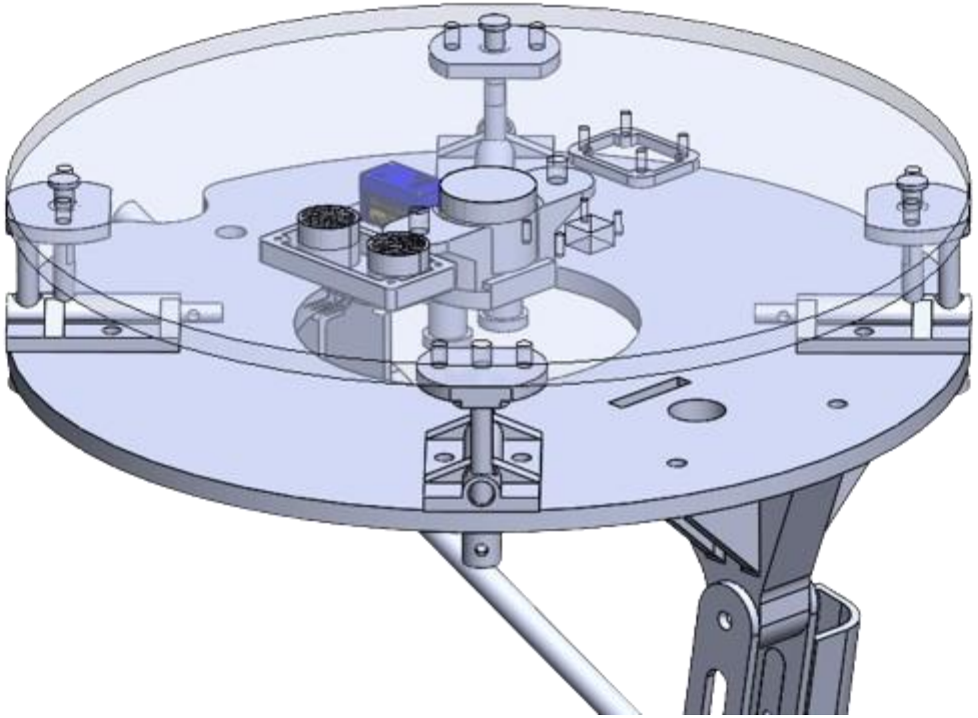
TOP PLATFORM

Innovative design

- Space for electronic components
- Introduce damping
- Z-axis motion
- Optimized for wire management

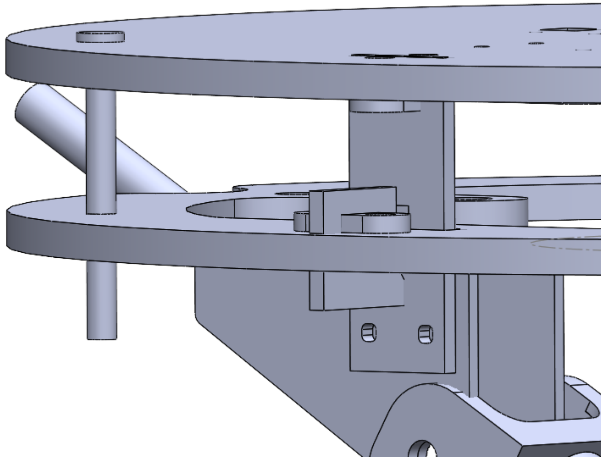
Acrylic Material

- Improved strength
- Better aesthetics

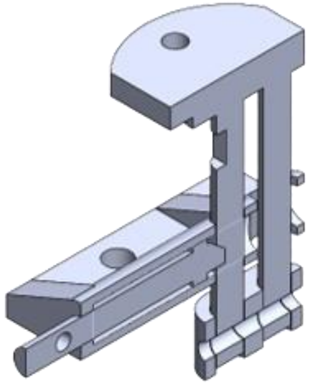


ACTIVE MECHANISM: DESIGN & APPROACH

TOP PLATFORM: HOLD-AND-RELEASE MECHANISM



Previous iteration



Latest iteration

MAGNECTIC PLATFORM

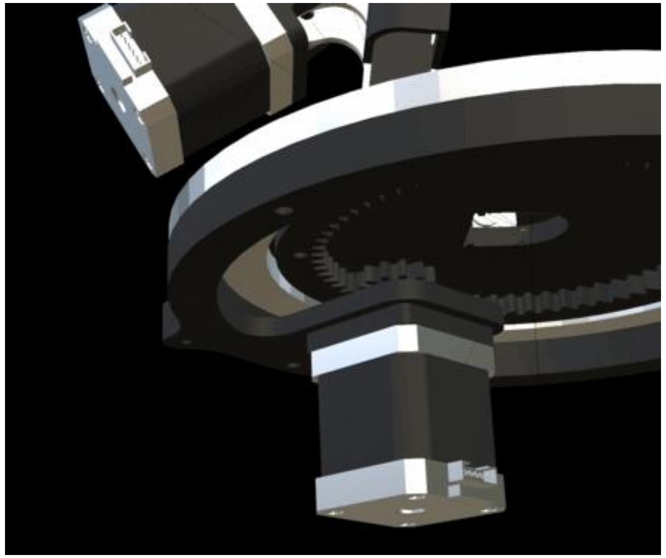
QUICK CAPTURE

- Spring-loaded piston to control compressed or extended state
- Spring integrated to hold the top layer and provide damping for abrupt landing
- Provide control to shoot top layer up to catch drone

ACTIVE MECHANISM: DESIGN & APPROACH

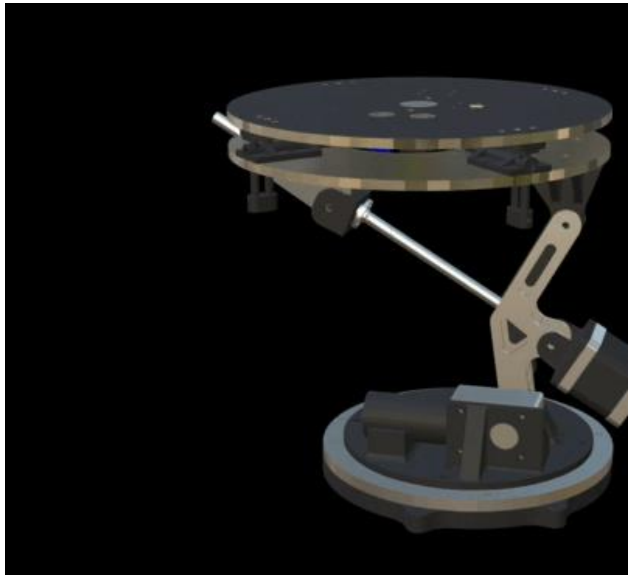
THREE DEGREE OF FREEDOM

360 DEGREE



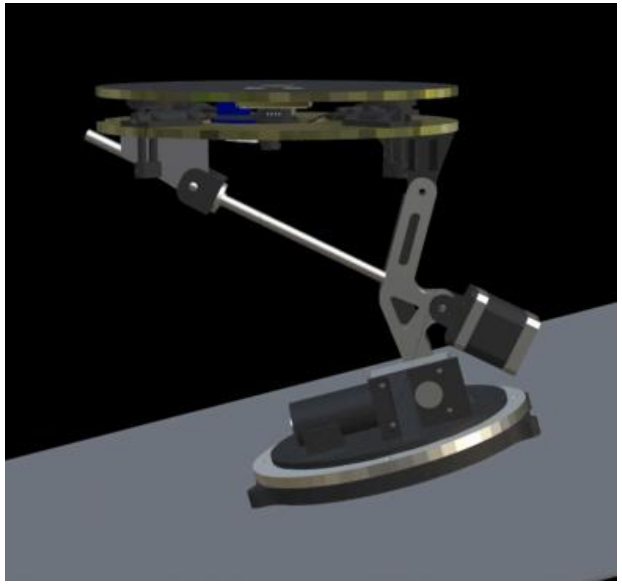
ROTATION

20 CM



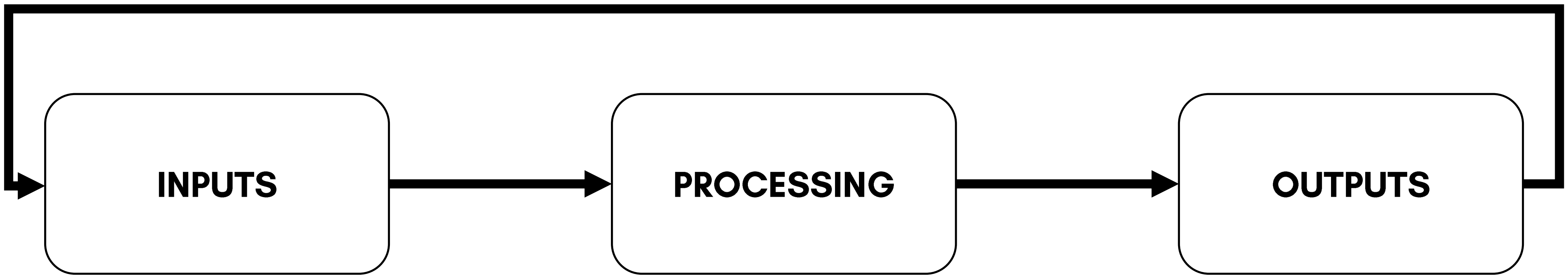
EXTENSION

-30 DEGREE **+50** DEGREE



INCLINATION

ACTIVE MECHANISM: DESIGN & APPROACH

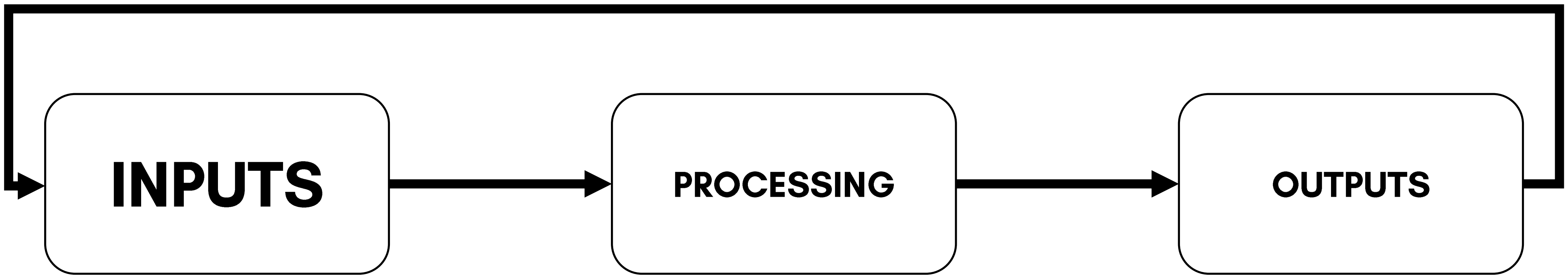


To detect the position of the drone
- Sensors
- Camera
- Others

To process data:
- Fast
- Accurate
- Able to facilitate connections between inputs & outputs

To move the platform to sensed position
- Motors
- Actuators

ACTIVE MECHANISM: DESIGN & APPROACH



Computer Vision

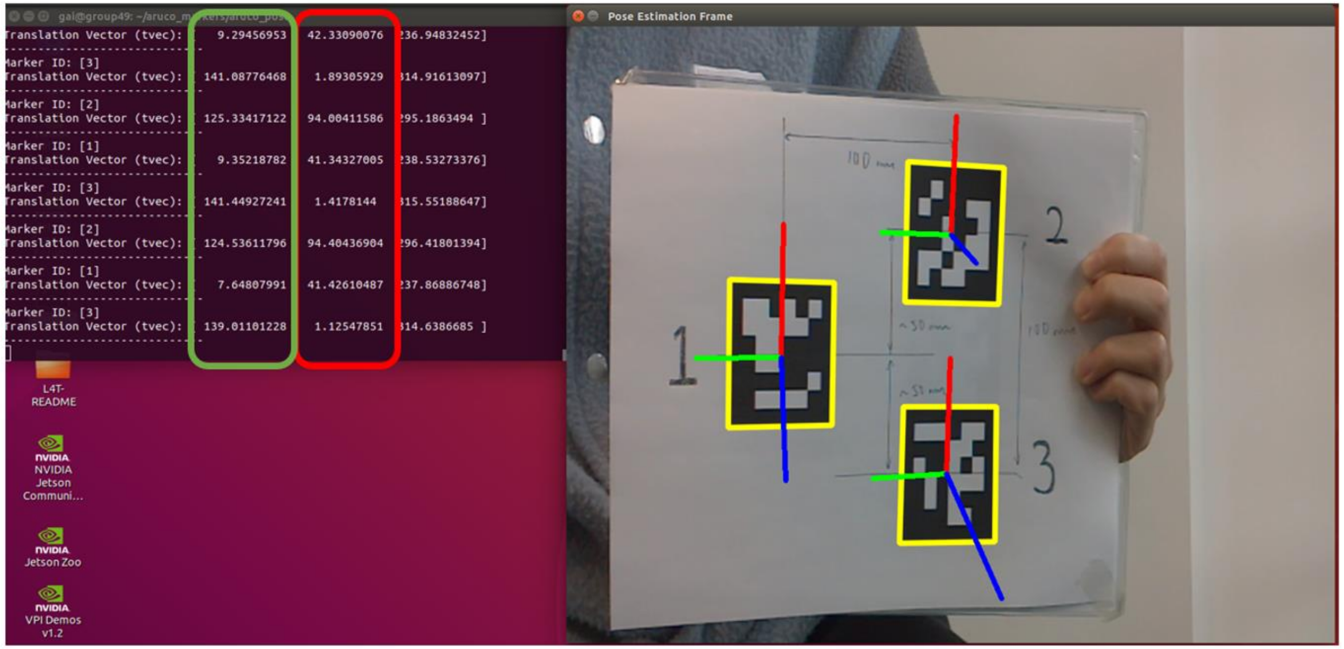
IMU

Ultrasonic

ArUco Marker | Computer Vision

Computer Vision

- Teach computers to interpret & understand visual info using photos or videos
- Using image processing & geometric calculations to obtain distance

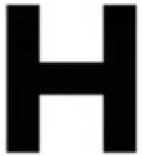


ArUco Marker | Computer Vision

DETECTION RATE

90%

ArUco markers



60%

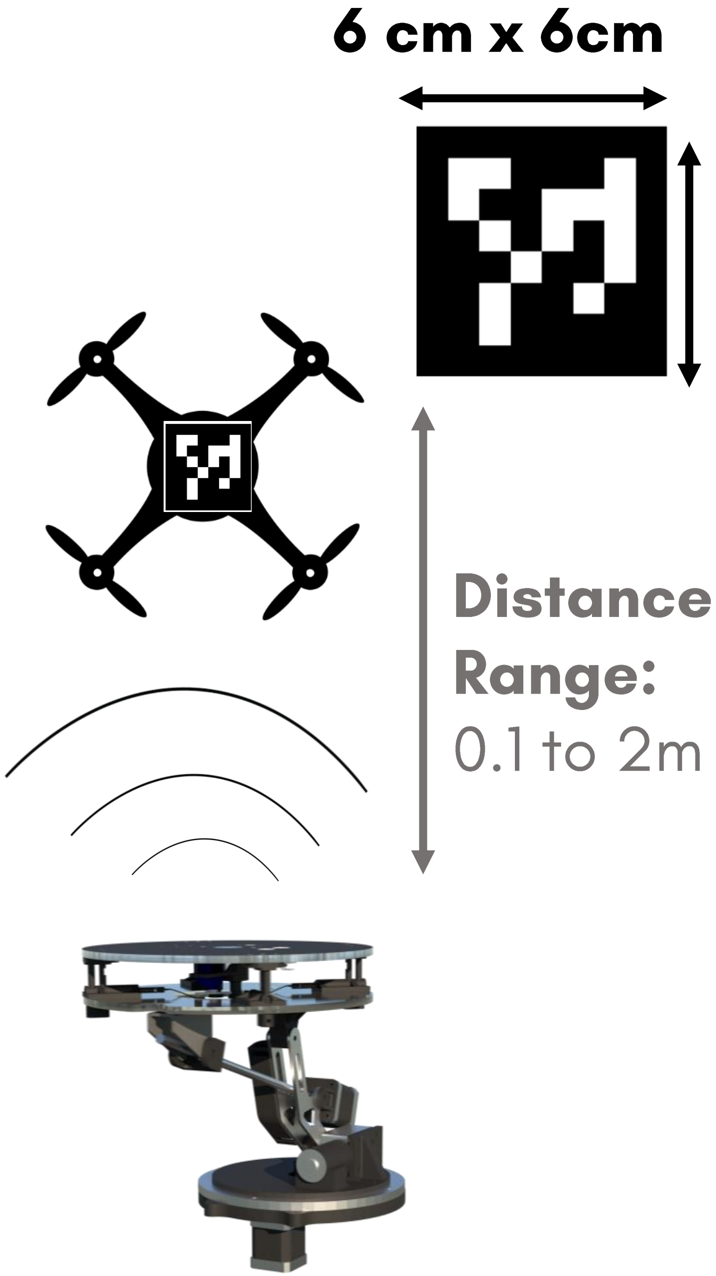
H markers

65%

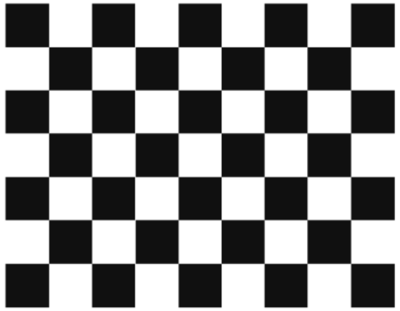
T markers

25%

Concentric Circles



ArUco Marker | Camera Calibration



CHESSBOARD PATTERN

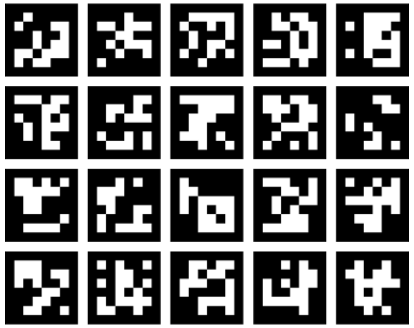
> 10 cm

error difference

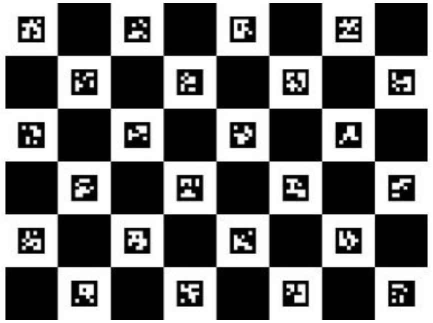
SINGLE ARUCO

> 8 cm

error difference



ARUCO BOARD



CHARUCO

3 cm

error difference

$\pm$ 3 cm

(x & y axis)

Precision

Computer-Vision-Based Tracking | Components

- **Raspberry Pi 4 (4 GB RAM)**
- **RPI Camera Module V2**

(+) Simple Implementation

(+) Supported with PWM pins

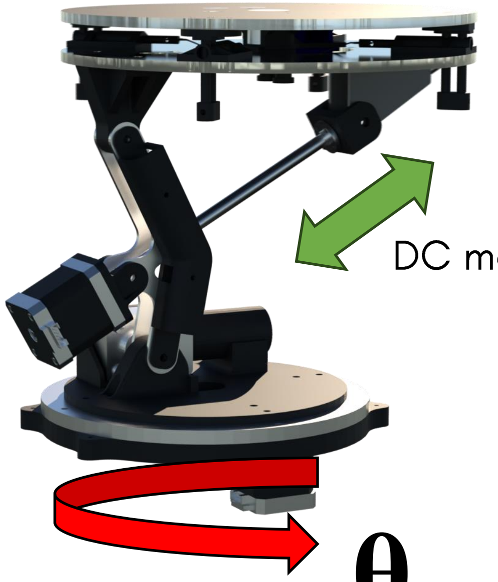
- **Jetson Nano**
- **IMX 219-77 Camera Module**

(+) Higher processing power

(-) No PWM pins

ArUco Marker | Pose Estimation

X,Y,Z ➡ R, θ

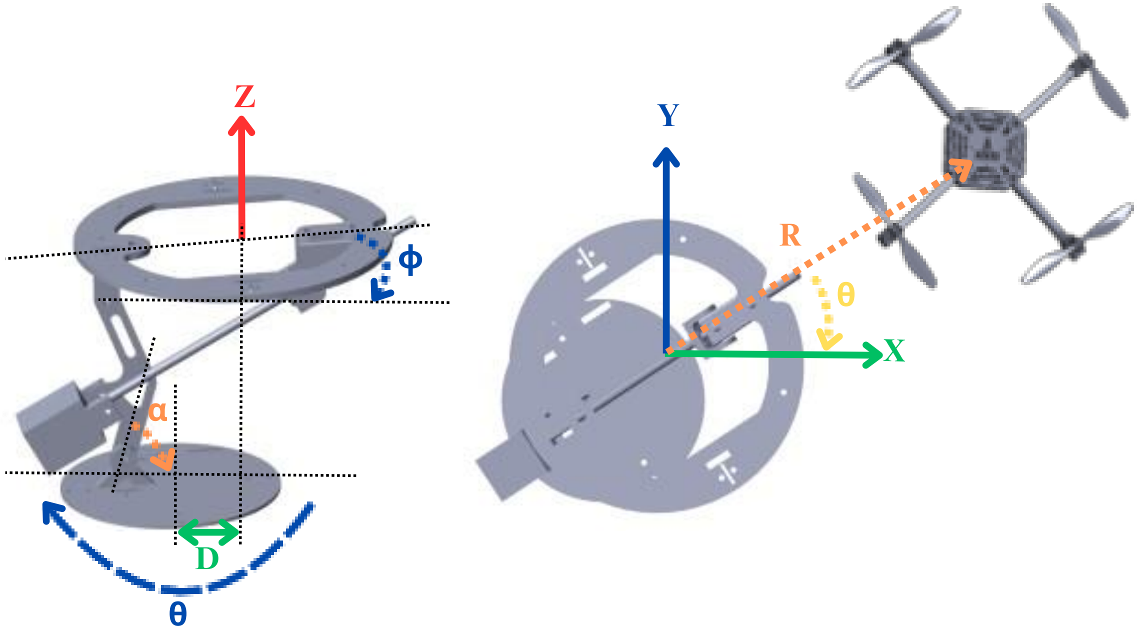


R

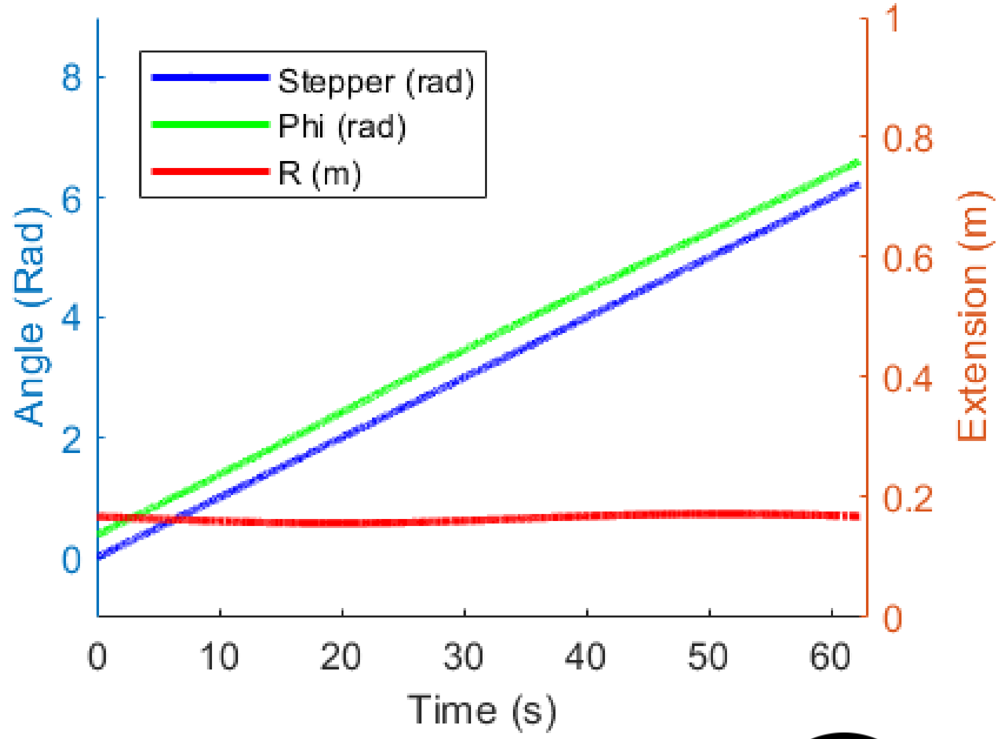
DC motor reacts to R

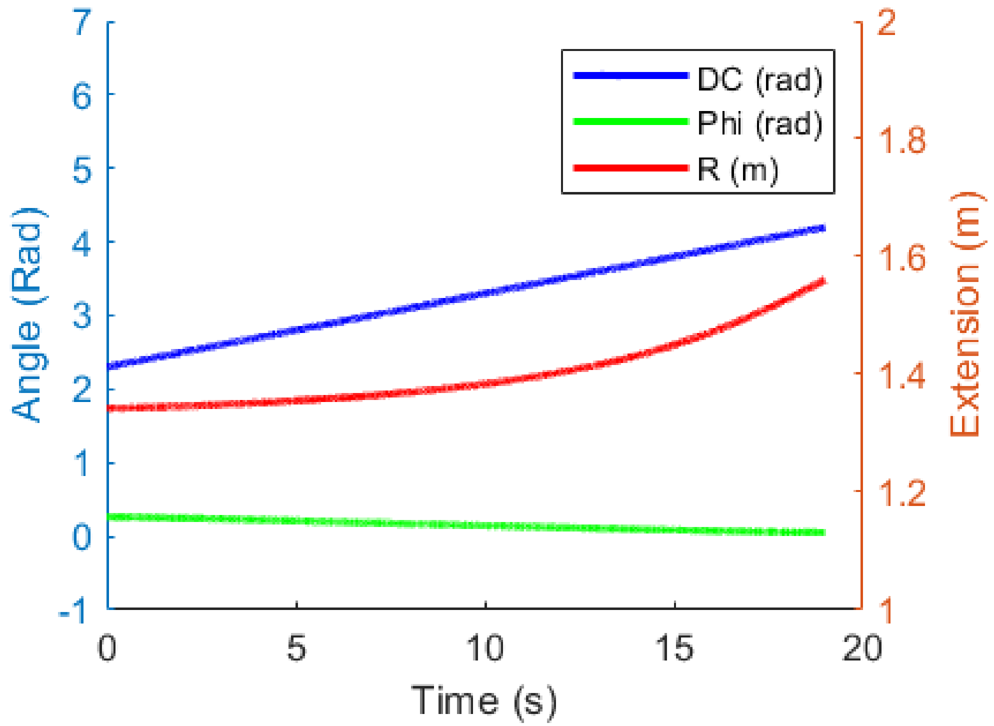
θ

Stepper Motor at base reacts to θ



ArUco Marker | Pose Estimation





Linear relationship with rotation, θ

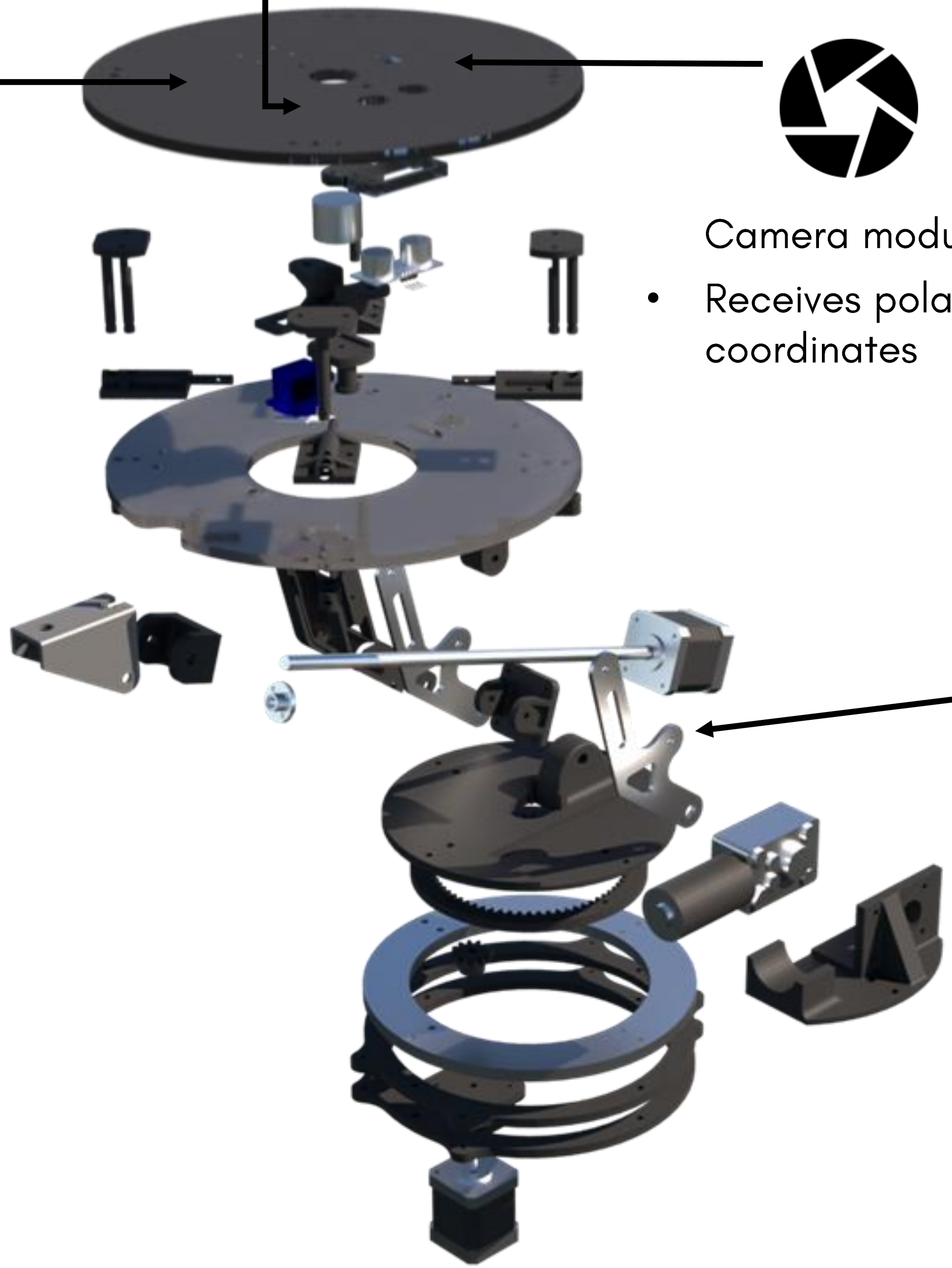
Stepper Motor

Only extension is affected

DC motor

IMU unit

- Measures the pitch of platform



Camera module

- Receives polar coordinates

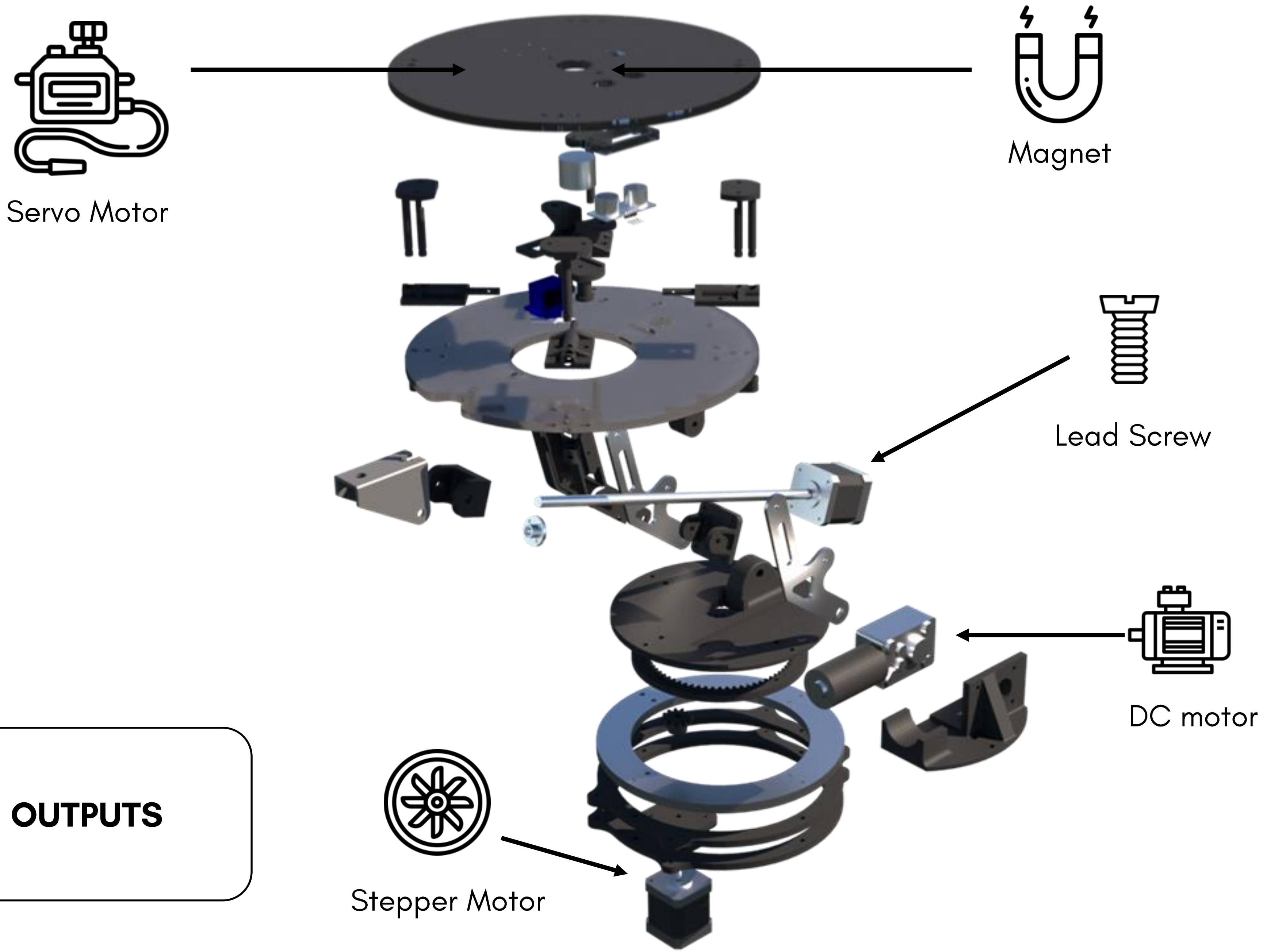
Ultrasonic sensor

- Detects height of drone

IMU unit

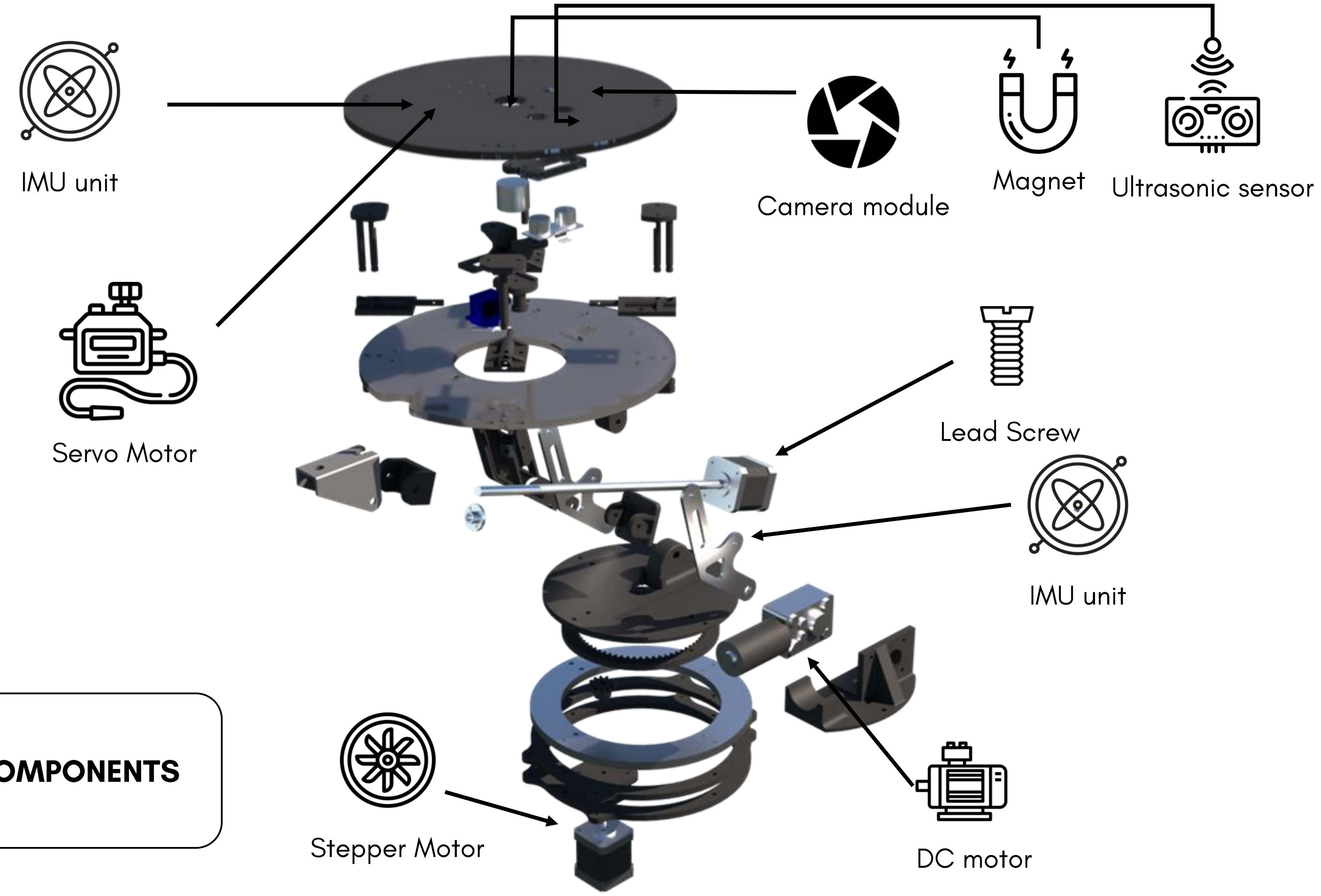
- Measures the roll of the arm

INPUTS



OUTPUTS

COMPONENTS


IMU unit
Camera module
Magnet
Ultrasonic sensor
Servo Motor
Lead Screw
IMU unit
Stepper Motor
DC motor

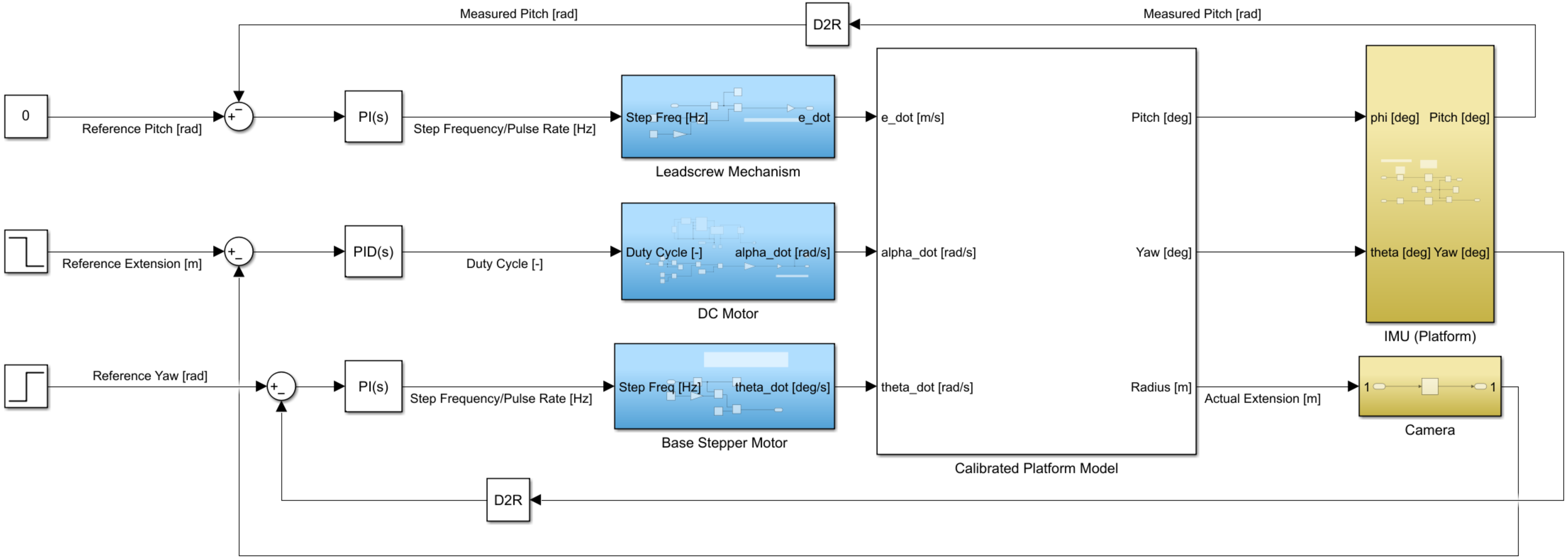
COMPONENTS

35 MINS FULL OPERATION

2 HOURS IDLE TIME

COMPONENTS

SIMULINK MODEL



SIMULINK MODEL – SENSORS & ACTUATORS

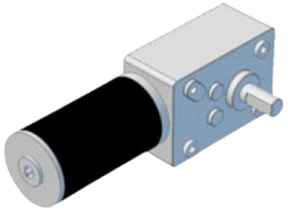
Sensors (IMU + Camera)

- IMU Modelled with delays and noise from sample rate, transmission, bus congestion
- Camera modelled as delays due to image processing time

Actuators

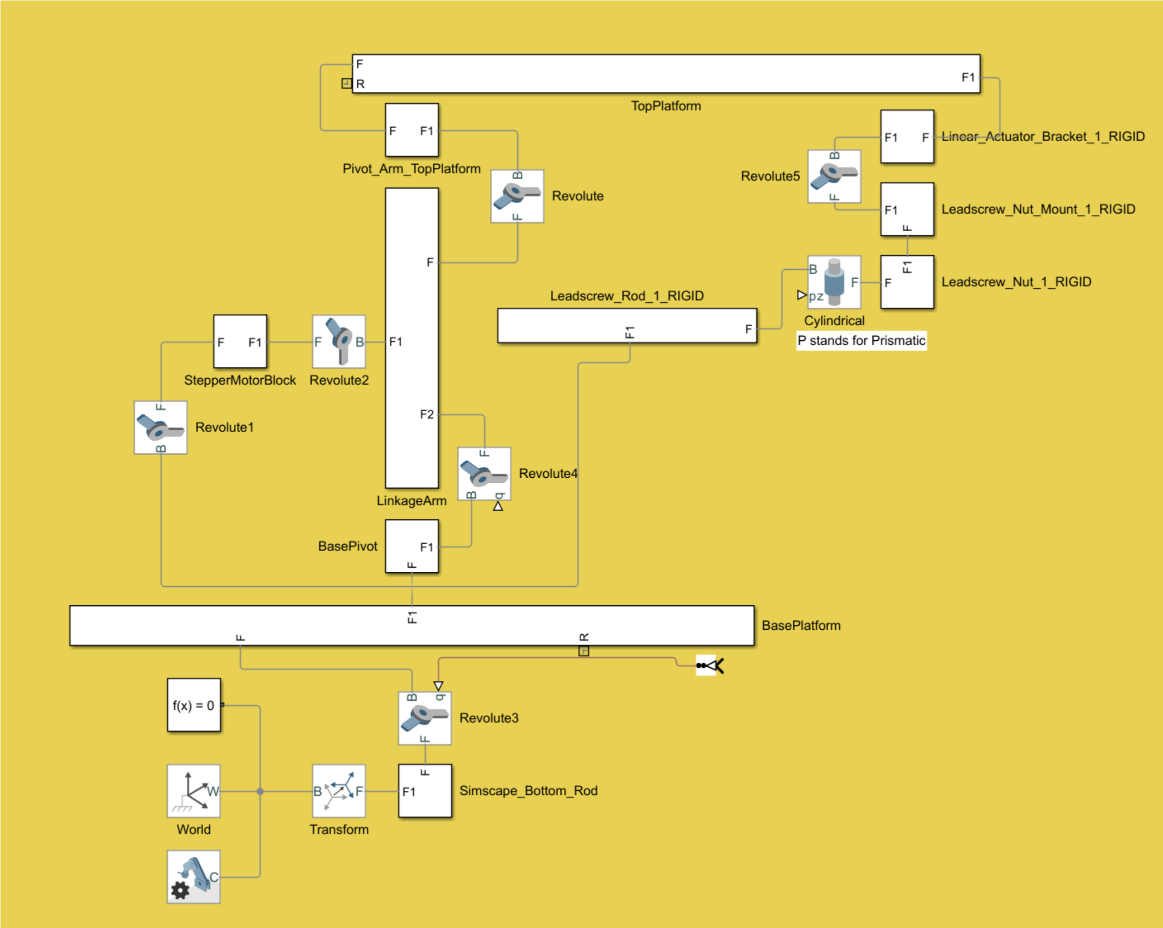
- DC motor modelled as equivalent electrical circuit, controlled via its duty cycle

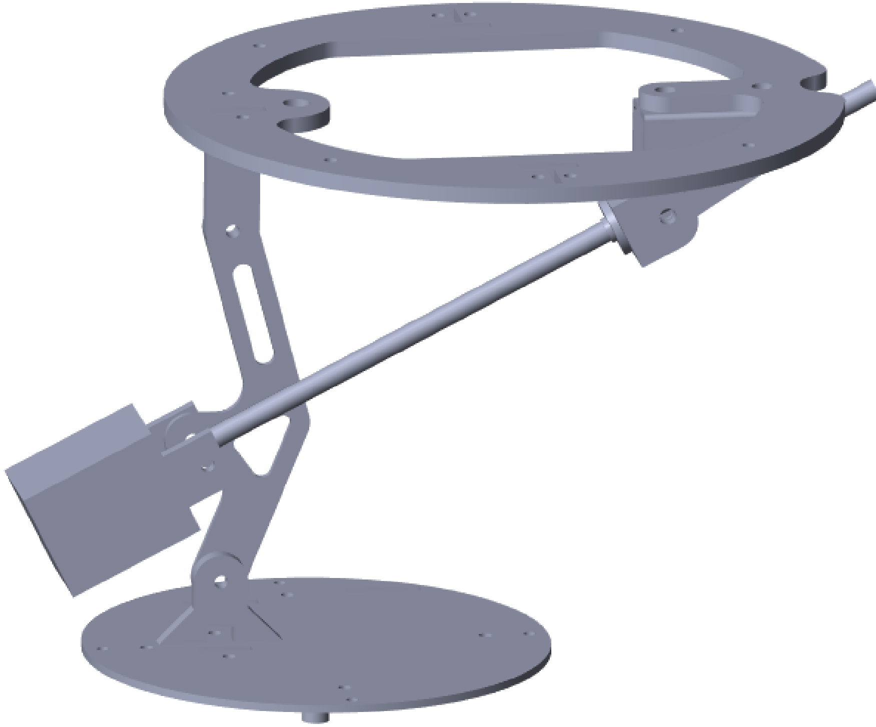
- Stepper motor modelled kinematically. Outputs angular velocity depending on the input step frequency


DC Motor


Stepper Motor

SIMULINK MODEL - PLANT





- CAD file imported into Simulink with Simscape Multibody Plugin
- Preserving kinematic and dynamics of the design

SIMULINK MODEL - CONTROLLER

Two popular methods of control – opted for **Proportional Integral Derivative (PID)**

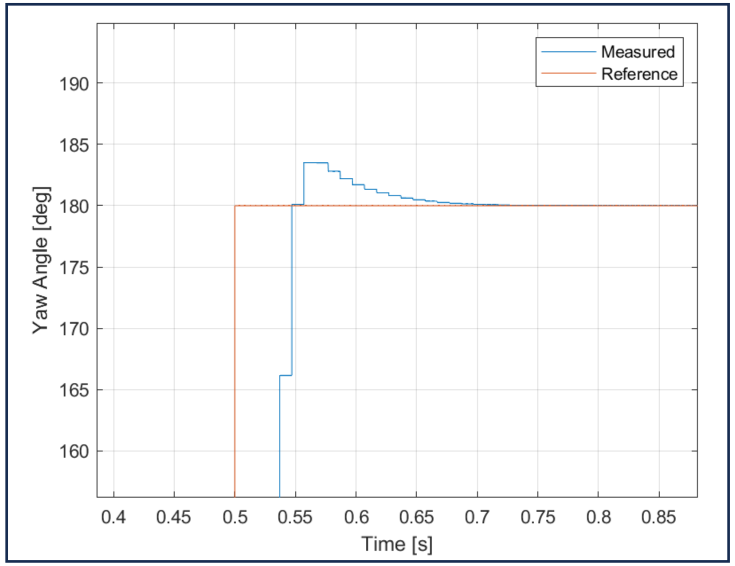
	Proportional Integral Derivative	**Model Predictive Control**
Advantages	• Fast response • Ease of Implementation	• Higher Accuracy • Predictive • Naturally handles constraints
Disadvantages	• Not well-suited for systems with non-linearity changes • Require additional logic for constraints	• Difficult to develop adequate model • Computational expensive

- Tuned with the aim of maximizing response rate to combat erratic nature of drones

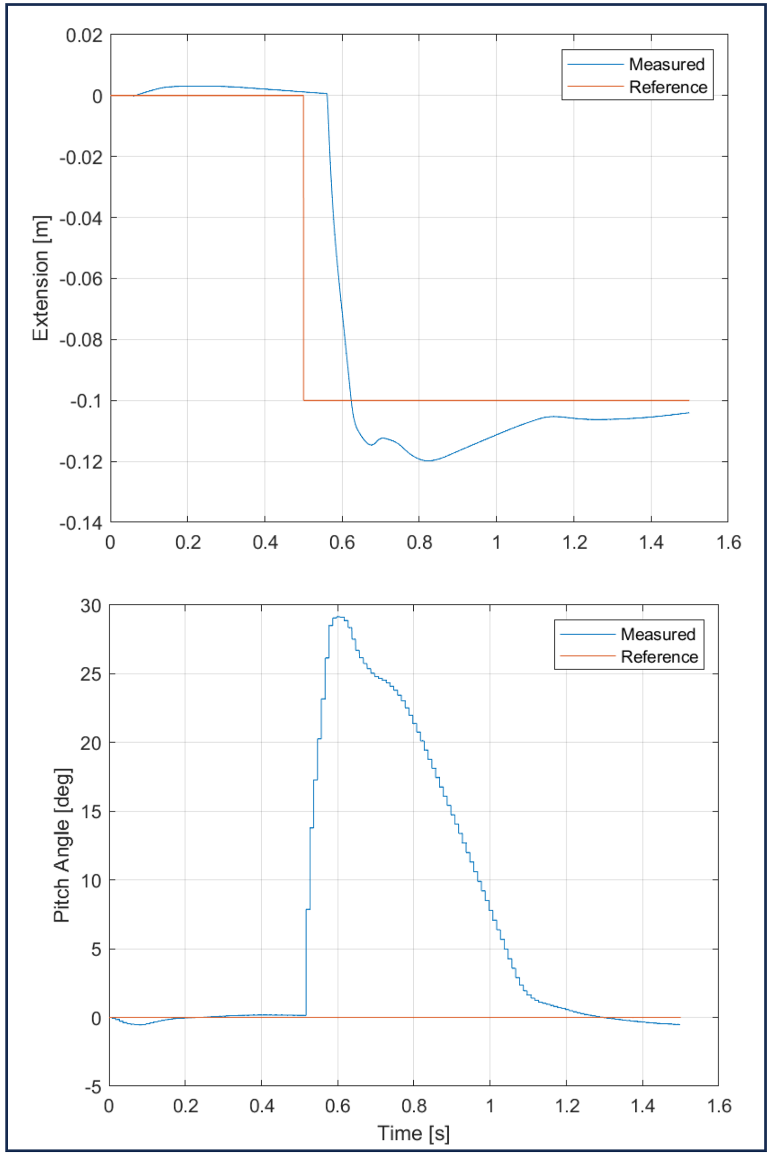
- Tuned heuristically with Ziegler-Nichols method

SIMULINK MODEL - CONTROLLER

Yaw

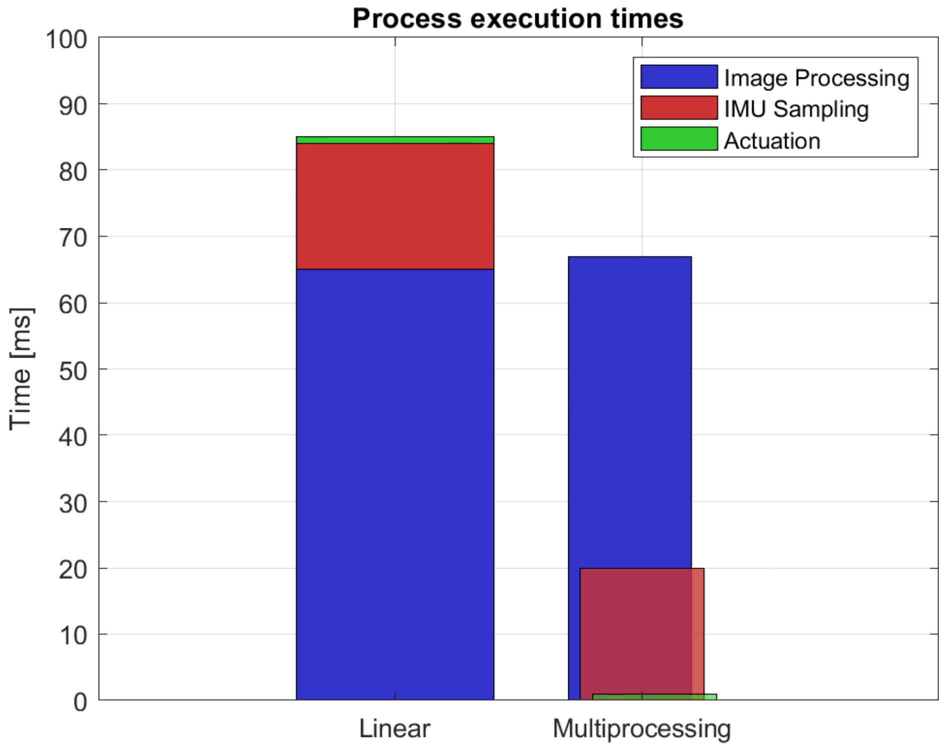


Extension and Pitch



- Requirements: 60 ms rise time and 10% overshoot
- Yield gain values as a starting point for the physical system
- Physical system requires additional tuning due to unmodelled non-linearities

REACTION TIME & MULTIPROCESSING



MULTIPROCESSING

Overall processing speed increased by **18%**

FAST REACTION TIME

67ms processing time

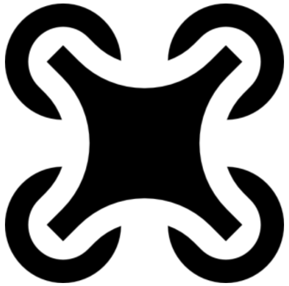
Self-levelling platform test

HOLD-AND-RELEASE MECHANISM TEST - SUCCESS

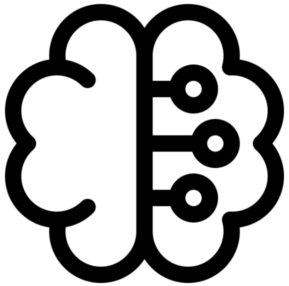
Hold-and-release Mechanism Test- Fail

Tracking test

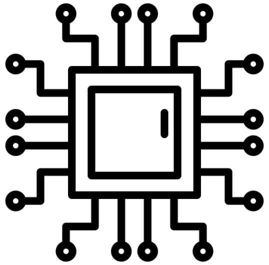
HARDWARE



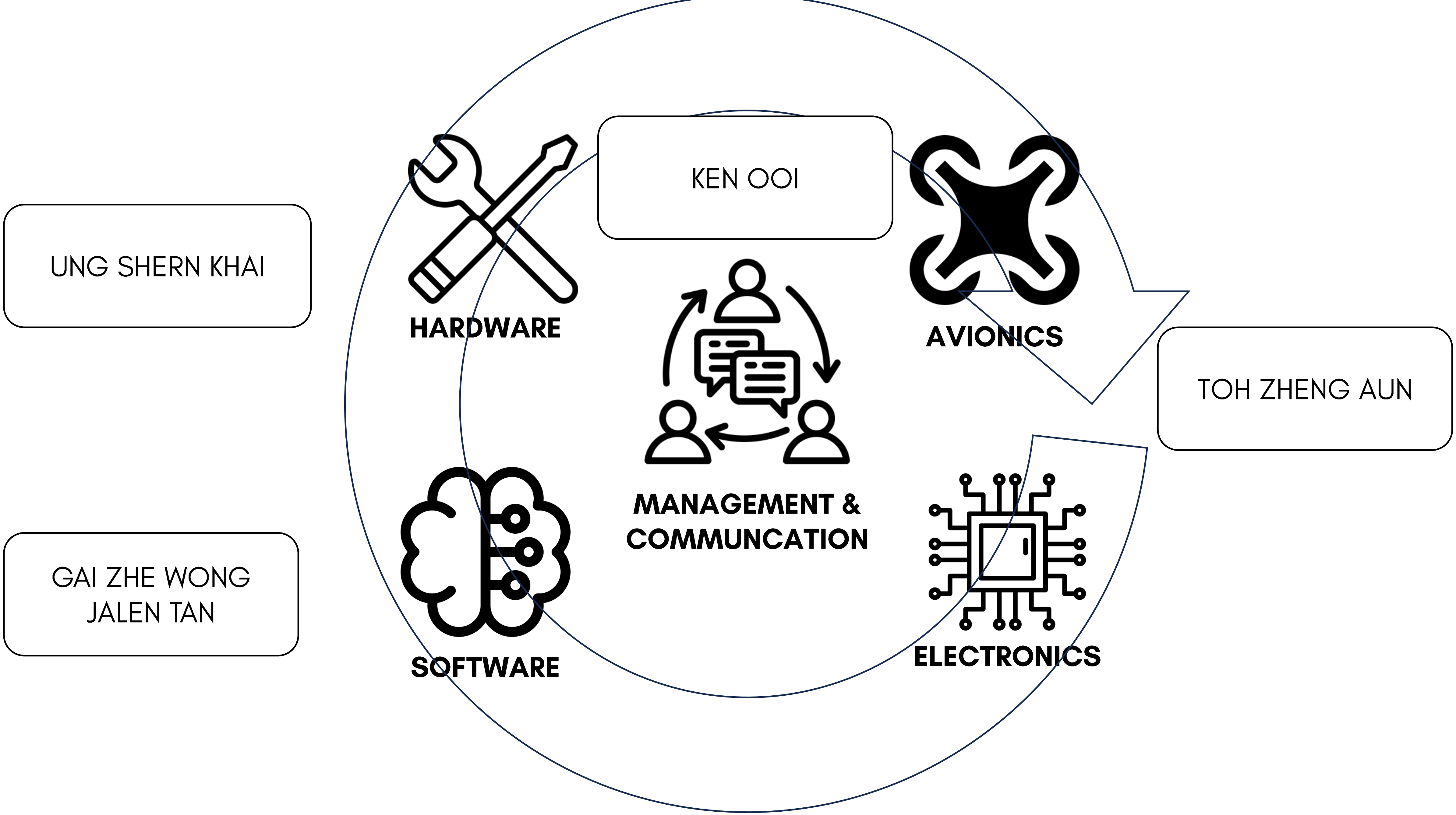
AVIONICS



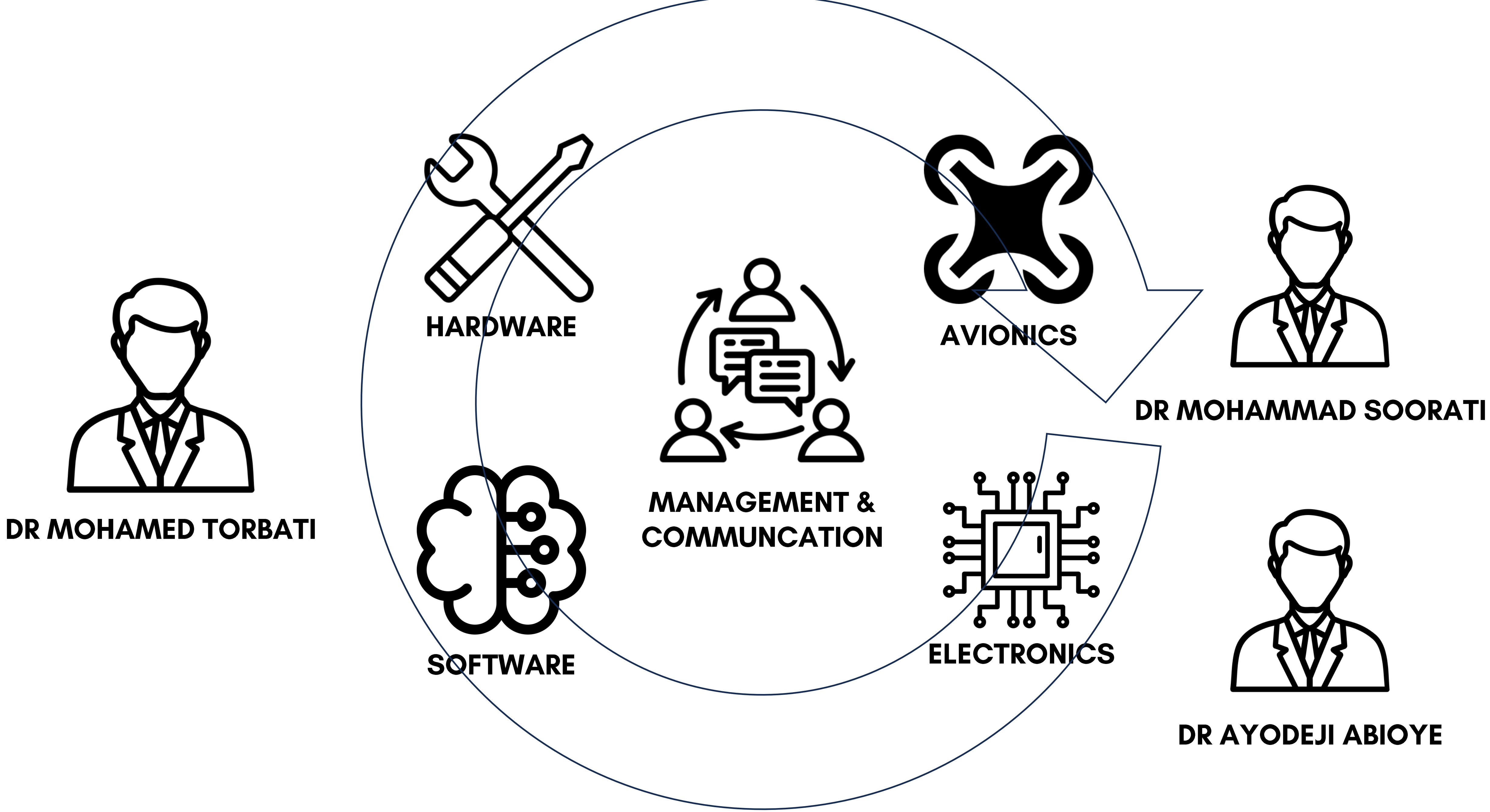
SOFTWARE

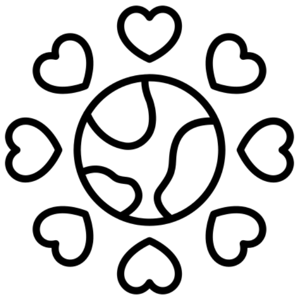


ELECTRONICS



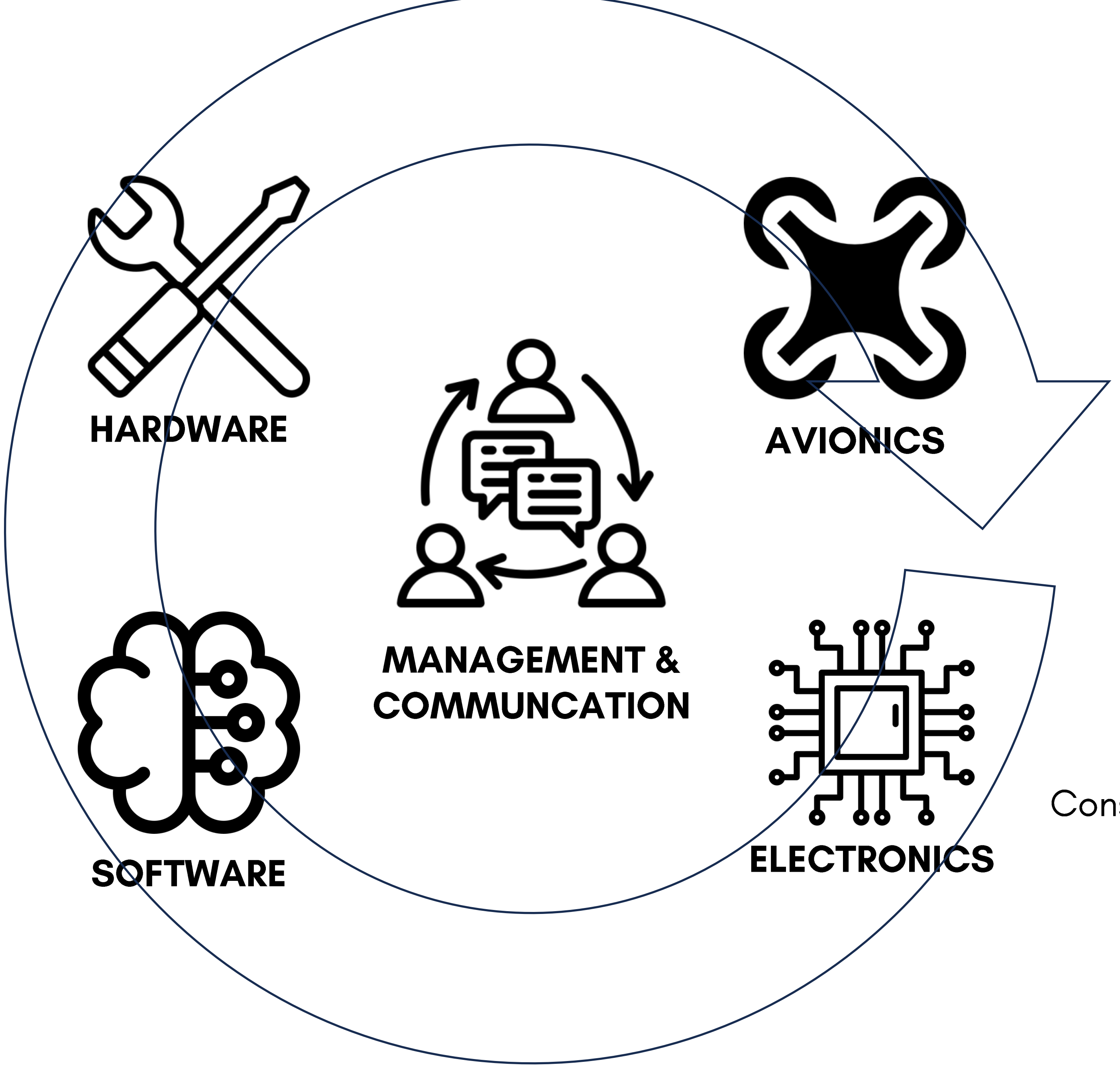
UNG SHERN KHAI
KEN OOI
TOH ZHENG AUN
GAI ZHE WONG
JALEN TAN
HARDWARE
AVIONICS
MANAGEMENT &
COMMUNCATION
SOFTWARE
ELECTRONICS


HARDWARE
AVIONICS
DR MOHAMMAD SOORATI
DR MOHAMED TORBATI
MANAGEMENT &
COMMUNCATION
SOFTWARE
ELECTRONICS
DR AYODEJI ABIOYE



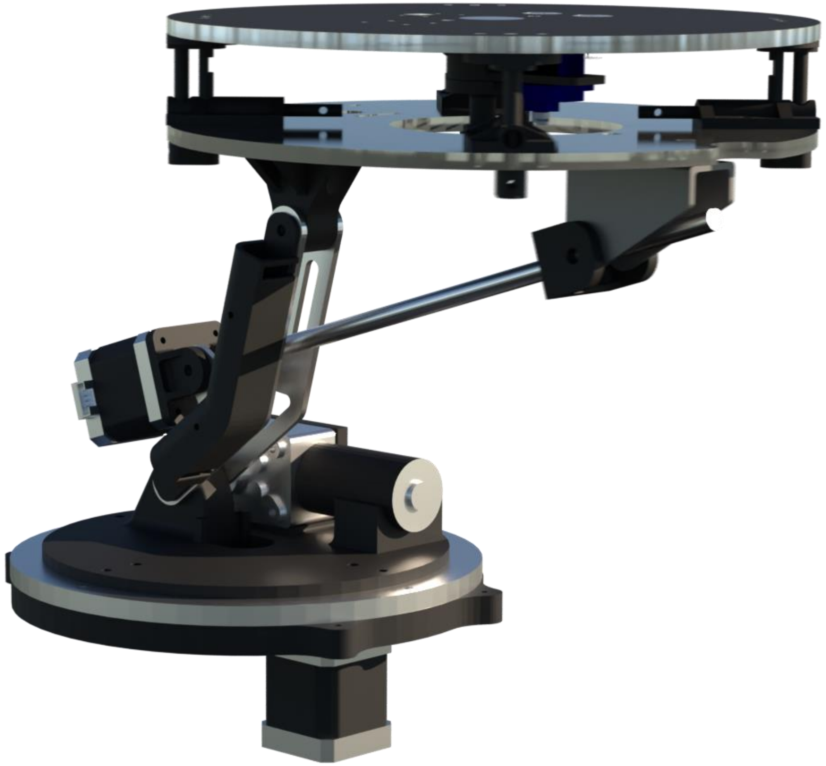
SUSTAINABLE

- Prototypes were made from sustainable material
- Scrap & recycled parts were used in our project



RESPONSIBLE

Conscientious Innovation

Hub for Aerial Navigation and Ground-based Autonomous Reconnaissance missions: *Model-1*

University of Southampton