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Master's degree in Applications and Technologies for Unmanned Aircraft Systems

MASTER THESIS

TITLE: Manoeuvring Drone (Tello ans Tello EDU) Using Body Poses or Gestures

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Abstract

The project aims to use computer vision and machine learning to control Tello and Tello Edu Drones.

The main use of this project is for educational and experimental purposes for upcoming future uses. I got inspired by the developments in the field of computer vision and pose estimation. As people are doing some much instructing and innovative things using this Drone and combined it with AI, Computer Vision, and Machine learning.

This project helps anyone who likes to learn from the beginning even they don’t have any prior knowledge of programming or Computer Vision. They can able to build a simple application and also provide the basic knowledge for the development of a more complex application. As a final objective, the main application is proposed, are consists of a drone that can be controlled using body poses or the movement of the body i.e., following the person by maintaining a constant safety distance and following the commands given by the instructor.

To start programming Tello or Tello EDU drone, it is based on a series of scripts and functions which is already been developed. So, that SDK is used as a guide to developing a new tello custom SDK to develop a complex and interactive application.

By using this custom template, we can develop several basic mission scripts/programs.

For the main application, different experiments were carried out to check which method is better in extracting the body key points/Landmarks in real-time in which low computing power is required or in other words no or less GPU power is required. As a result, I come across the Google AI open source “MediaPipe Machine Learning” platform, which provides a cross-platform, customizable ML solution for live and streaming media. Which is used for advanced application in this project.

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INTRODUCTION

This project focus on the Tello and Tello EDU Drones. As both are being used for experimental and educational purposes by several companies, institutes, and universities. They provide an easy, simple, and reliable platform for beginners to start learning.

As there are various other drones also available in the market, which are also dedicated for educational and experimental purposes have been studied and how the people and organizations used them. During this, it’s found that Tello and Tello EDU Drones are best for this project. There is various GitHub repository available online related to both drones. In addition, there is a forum called “Tellopilots” where many people and different developers share doubts, problems, and progress, which helps me and many other beginners to learn and to avoid future mistakes. Besides that, on “YouTube” also there is lots of content and tutorials are available which help me to learn during this project.

The initial objective of the project is to create a basic platform that allows anyone to perform basic missions with or without using the Body Poses. These basic missions consist of simple takeoff, landing, or any serious of movements. As we proceed further in the project it also explains or elaborates to create more complex applications. But the main objective of this project is to control the drone movements through body poses, although it also includes tracking or following the body/person by maintaining a safe distance. There will be many more applications that can be developed by using this basic platform.

The drones to carry out this project are provided by the Universitat Politecnica de Catalunya campus “Castelldefels School of Telecommunications and Aerospace Engineering (EETAC)” and the “elarco design SL.” a consultancy company with whom I proceed my Master’s Thesis. Moreover, they also provide the proper space and controlled area to perform various tests throughout this project along with proper mentoring.

To start this project, I used Tello SDK. It contains several packages, each with one or more classes that present the data and methods used to control a Tello drone. And, MediaPipe BlazePose GHUM & GHUML python API which provide a basic platform to work on this project. It contains a lightweight convolutional neural network architecture for human pose estimation that is tailored for real-time inference on mobile and low-end devices. As MediaPipe also provides the same API for other platforms like android, iOS, C++, and Java. Along with some other basic python libraries.

This document is organized in various chapters for a better understanding of the process of the project and the knowledge for those who want to start their new projects. Chapter 1 is discussed about the various drones which are available in the market which can be customized and programmed according to the user for this application. Chapter 2 is focused on the in-depth explanation of Tello Drone i.e., technical characteristics, a concept before starting programing, accessories, and more. Chapter 3 is focused on the explanation and the working pipeline of the MediaPipe BlazePose. Chapter 4, is focused on the programming and integration, the knowledge that I gained from the previous chapters to develop the main application. Finally, a conclusion.

All the references and research which provide knowledge and motivation to make this project are referred to below in references and annexure. Also, the material related to this project is available online on GitHub [15].

CHAPTER 1: STATUS QUO

An investigation or a search was carried out before starting this project to know about the available platforms in the market, which can be adopted easily and have versatility for an educational project.

Several drones have similar characteristics and specifications which can be suitable for this project. The most convenient comparisons that have been selected are discussed below.

Parrot Mambo (Fig. 1.1) is a brilliant little mini drone which is developed by “Parrot” [4]. This drone is the most stable and easiest to pilot for new drone flyers. The great thing about this is that it comes with an array of sensors including a gyroscope, air pressure sensor, ultrasonic sensor, and an Excel matter. This means that the mambo fly can detect objects and conditions in the environment which you can use as triggers for your programming language such as JavaScript, Matlab, or Python.

Fig 1.1 Parrot mambo

Crazyflie (Fig. 1.2) is a small quadcopter, which is developed by “Bitcraze” [5]. This drone is small with as few mechanical parts on a PCB and the main mechanical frame with motors glued to the PCB. Which makes this the smallest quadcopter in the world. It has a durable design with easy to assemble without any soldering parts like Tello. It supports various platforms like iOS, Android, Windows, Mac, OSX/Linux and is compatible with Python language.

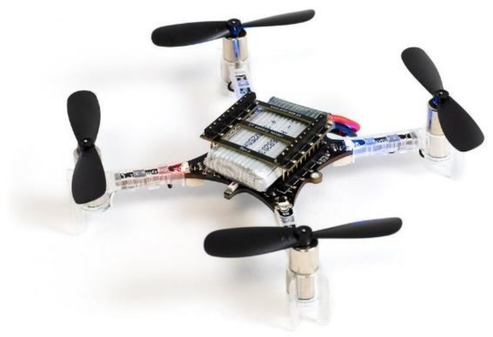


Fig 1.2 Crazyflie

Codrone [Fig. 1.3], is also a small drone developed by “Robolink” [6]. This programmable drone is specially focused on education purposes with an attractive look to attract youngsters. It supports two programming platforms Arduino and Python.

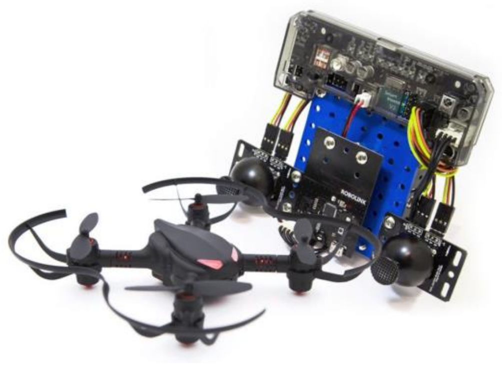


Fig 1.3 Codrone

Flybrix [7] (Fig. 1.4), is a Lego Drone. Unlike the drones mentioned above and the Tello, this drone is buildable, without having to need extra tools, which add a new set of learning. This drone can be programmed through Arduino.

Fig 1.4 Flybrix

Except for this drone, the above-mentioned have the option of block programming, just like Tello.

The potential of Tello and Tello EDU for education purposes is very large, that’s why several companies are using them. Among them we can highlight a few:

DrobotsCompany [8]: It is a company that operates in several states of the United States. It is dedicated to courses for young people. Among its activities, it is worth mentioning the realization of missions with the Tello and Tello EDU drone, which makes young people have fun while they learn.

Campuse [9]: It is a company that operates in various parts of the world. They are specialized in giving courses related to new technologies. Its courses include the use of the Tello and Tello EDU drone to learn to program in Python and use OpenCV.

Its easy programming has allowed developers to develop different applications:

DroneBlocks [10]: It is an application that allows programming in a very simple way with blocks.

Tello FPV [11]: It is an alternative application for drone control but it offers many more features than the application developed by RYZE. This application is not free.

CHAPTER 2: TELLO DRONE

Tello EDU and Tello (Fig. 2.1) is a perfect programmable drone for educational, DIY, and hobby use. In this section, the drones, their characteristics, and other information necessary for the development of applications will be known in more depth.

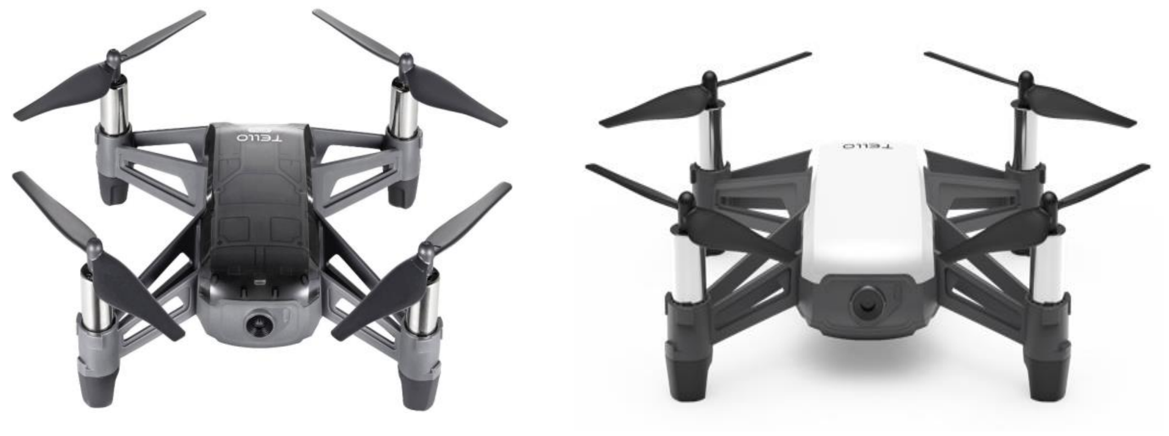


Fig. 2.1 TELLO EDU and TELLO Drone

Both are made by Shenzhen Ryze Technology and incorporate DJI flight control technology and Intel processors.

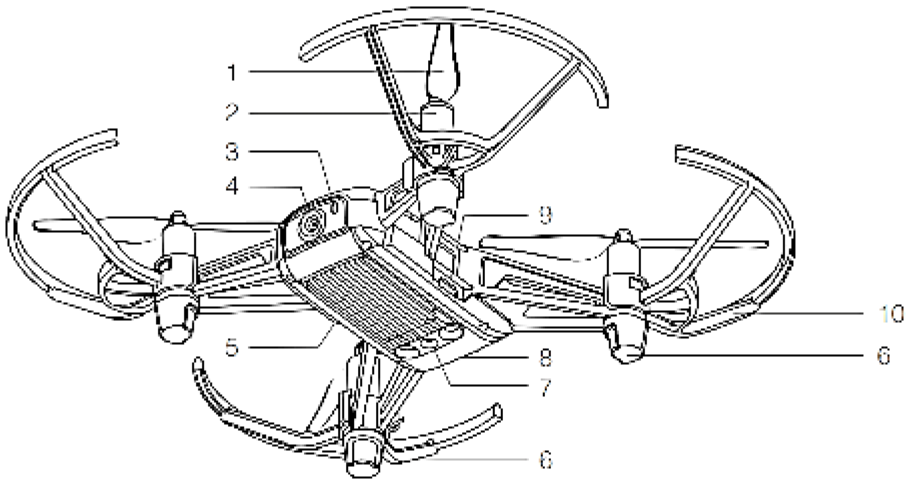
Tello is the first drone that they put on the market and Tello EDU is the latest version with a few more features and which allow swarm programming in a simple way than the previous version.

This new version also has a new SDK which is more widespread than the previous one [13] [14].

2.1. Technical Characteristics

The principal components of the drone are the following:

Table 2.1 Description of components of the Tello EDU drone

	
1. Propellers	6. Antennas
2. Motors	7. Vision Positioning System
3. Drone Status Indicator	8. Battery
4. Camera	9. Micro USB port
5. Power Button	10. Propeller protectors

Its dimensions and characteristics make it very manageable.

Table 2.2 Dimensions and characteristic

Weight	87 g
Dimensions	98×92.5×41 mm
Propeller	3 inches
Integrated Functions	Telemetric sensor
	Barometer
	LED
	Vision System
	Wi-Fi 2.4 GHz 802.11n
	Real-time streaming 720p
Port	USB battery charging port
Operating temperature range	from 0º to 40º C
Operating frequency range	from 2.4 to 2.4835 GHz
Transmitter (EIRP)	20 dBm (FCC)
	19 dBm (CE)
	19 dBm (SRRC)

Being a drone for mainly indoor use, it can be used outdoors but in a controlled environment like weather, wind speed, etc., that's why the characteristics that define its operations are quite limited.

Table 2.3 Detail in operation

Maximum distance of the flight	100 meters
Minimum speed	6.7 mph (10.8 kph)
Maximum speed	17.8 mph (28 kph)
Maximum flight time	13 min (0 wind at a consistent 9mph (15kph))
Maximum flight height	30 meters

It has a very easy battery to change; it can be charged directly with a USB cable with the battery inside the drone, or with a charging hub.

Table 2.4 Battery details

Removable	Yes
Capacity	1100 mAh
Voltage	3.8 V
Type	LiPo
Energy	4.18 Wh
Net Weight	25 ± 2 g
Temperature range when charging	from 5º to 45º
Maximum Load Power	10 W

The camera allows us to obtain video with a good quality (HD), after the image processing, it is possible to develop different applications.

Table 2.5 Camera details

Photo	5 MP (2592x1936)
Field of view	82.6°
Video	HD: 1280 X 720 30 fps
Format	JPG (Photo)
	MP4 (Video)
Electronic stabilization	Yes

Vision Positioning System: Consisting of a camera, which is a grey-only 320x240 IR-sensitive and an infrared 3D module. This system is capable of working in a range of 0.3 m to 30 m high, but its optimal working conditions are 0.3 m to 6 m high.

Drone Status Indicator: It is a led that has the drone, and indicates in what state the drone is in each moment.

Field of view: It is the open observable area that the drone camera can see.

Electronic stabilization: It is an image enhancement technique using electronic processing.

2.2. Basic Requirement for programming

We can program the Drone by using a different platform, operating system, and programing language.

The platform like Visual Code, PyCharm, Anaconda, etc.

An operating system like Windows, Linux, MAC, etc.

Programing languages like Java, C++, Python, Scratch, etc.

But in this project windows have been used along with Python programming language due to easily available python libraries

To run a script, it is necessary to connect the computer with the Drone Wi-Fi. The name of the Wi-Fi network of the drone is set by default which is written on the drone where we put the battery, but it is possible to change the name of the network and also add a password to prevent any stranger from taking control of the drone in the script.

2.3. SDK 2.0

The Tello drone has a software development kit, which helps to understand the different commands that are accepted by the drone. This serves as the basic structure for the development of an application. You can find more detail on the internet in the user guide and git repository [12].

2.3. Mobile Application

Shenzhen RYZE Tech Co. Ltd. Has developed an application for the Tello, which creates a platform to control the drone over Wi-Fi manually. This application displays all the necessary information on the display of an Android or iOS mobile (Fig. 2.2).

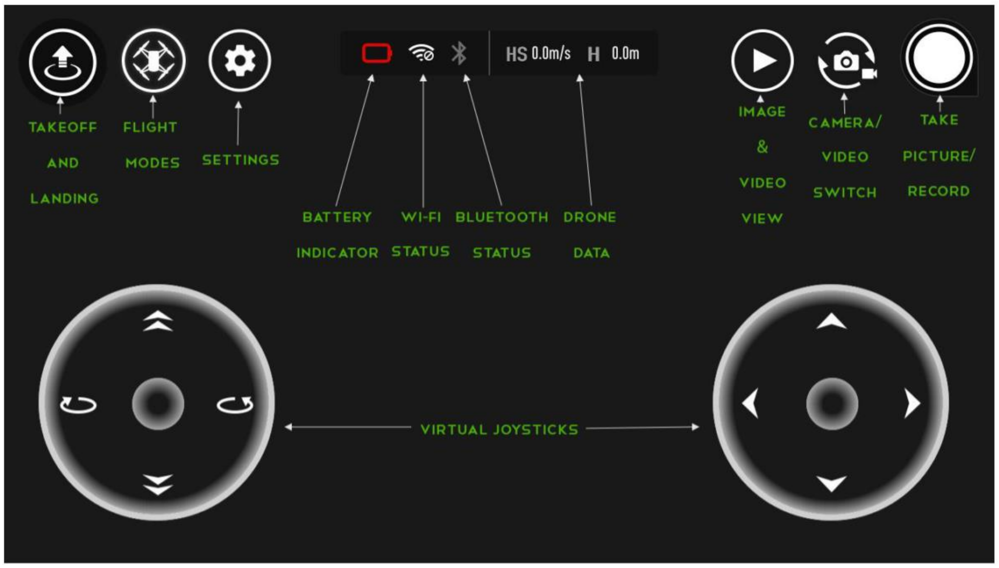
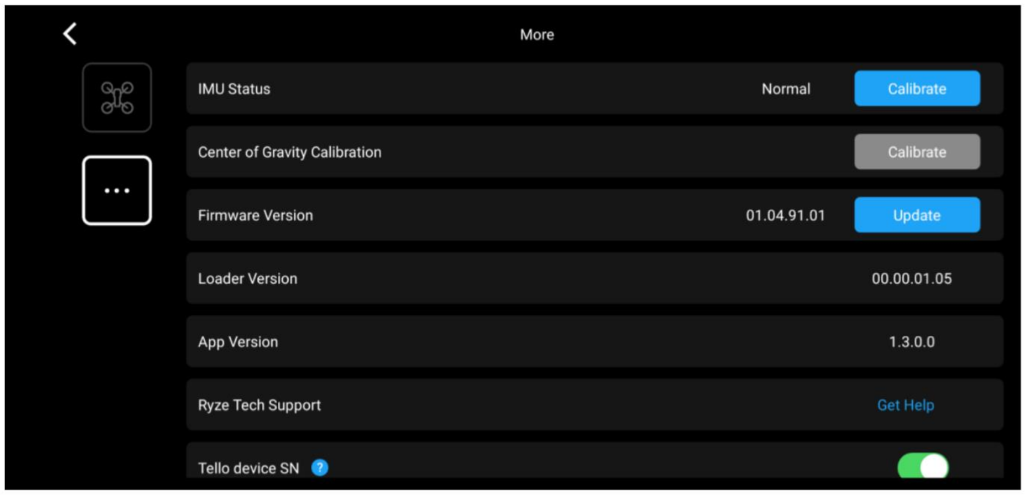


Fig. 2.2 Tello App Display

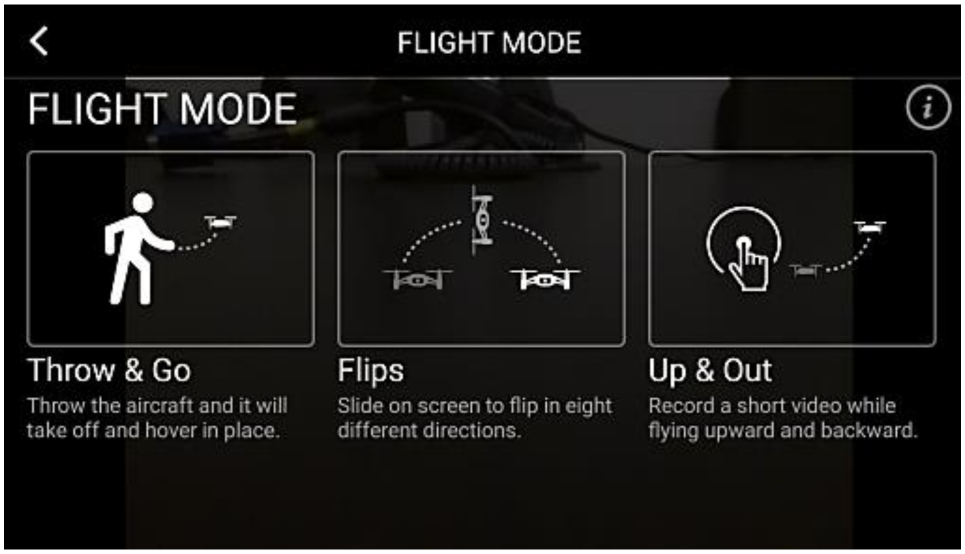


IMU Status	Normal	Calibrate
Center of Gravity Calibration		Calibrate
Firmware Version	01.04.91.01	Update
Loader Version	00.00.01.05	
App Version	1.3.0.0	
Ryze Tech Support	Get Help	
Tello device SN		

Fig. 2.3 Tello App advance option

This application also allows you to Calibrate and update the Firewall of the Tello (Fig. 2.3).

Moreover, this app has various predefine flight modes which allow you to perform various tasks and basic missions (Fig. 2.4 and Fig. 2.5).

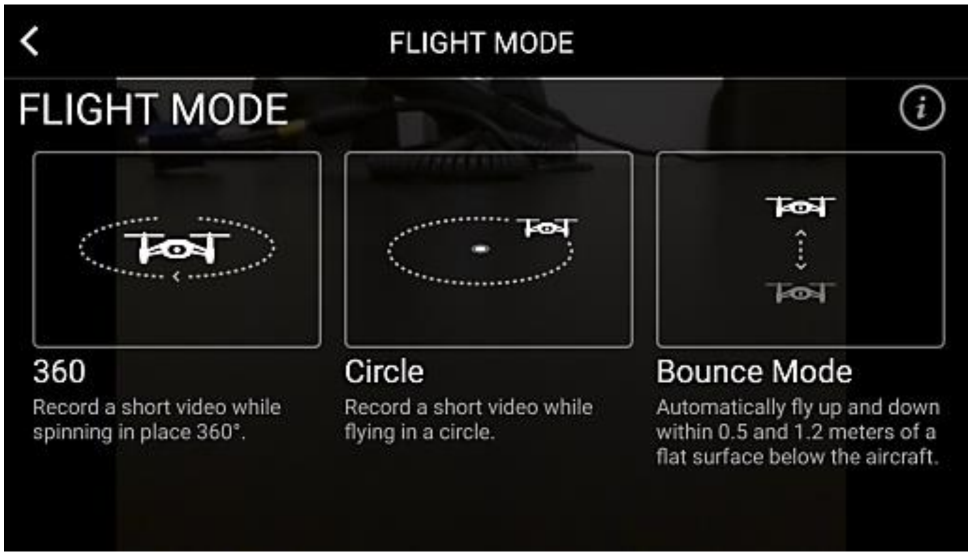


Throw & Go
Throw the aircraft and it will take off and hover in place.

Flips
Slide on screen to flip in eight different directions.

Up & Out
Record a short video while flying upward and backward.

Fig. 2.4 Flight Mode_1



360
Record a short video while spinning in place 360°.

Circle
Record a short video while flying in a circle.

Bounce Mode
Automatically fly up and down within 0.5 and 1.2 meters of a flat surface below the aircraft.

Fig. 2.5 Flight Mode_2

CHAPTER 3: POSE DETECTION

In this chapter, we talk about Person/Pose detection, as we know there are various 2D and 3D open-source pose estimation models or frameworks are available in the market, like OpenPose, CPN (Cascaded Pyramid Network), AlphaPose, and HRNet (High-Resolution Net), Deep Pose, Pose Net, Dense Pose. Each model has its pros and cons, and data output which can be used in various applications. For this project, I do some research over the internet and also read some research papers. After doing this intensive research I came across a new 2D & 3D real-time lightweight pose estimation framework which was purposed by Google in CVPR Workshop on Computer Vision for Augmented and Virtual Reality at Seattle USA in June 2020. This framework is named “MediaPipe Pose”. It is also called BlazePose. This lightweight 3D framework also supports cross-platform (i.e., Android, iOS, web, edge devices) compatibility.

In addition, the output of this model match my specification for this project, that’s the reason I decided to use this Pose mode and we are going to know about this in more detail as we proceed further in the chapter.

Moreover, MediaPipe also provides several other frameworks and ML models like Face Detection, Multi-hand Tracking, Hair Segmentation, Object Detection, and Tracking, Objectron: 3D Object Detection and Tracking, Auto Flip: Automatic video cropping pipeline, Pose Detection and more.

3.1 BlazePose Overview

Human pose estimation plays a critical role in various applications such as physical exercises, sign language recognition, and full-body gesture control. For example, it can form the basis application platform for yoga, dance, and fitness. It can also enable the overlay of digital content and information on top of the physical world in augmented reality. That makes it challenging due to the wide variety of poses, numerous degrees of freedom, and occlusions.

Recent work [18] [19] has shown significant progress on pose estimation. The common approach in this work is to produce heatmaps for each joint along with refining offsets for each coordinate. While this choice of heatmaps scales to multiple people with minimal overhead, it makes the model for a single person considerably larger than is suitable for real-time inference.

In contrast to heatmap-based techniques, regression-based approaches, while less computationally demanding and more scalable, attempt to predict the mean coordinate values, often failing to address the underlying ambiguity. Newell et al.

[20] have shown that the stacked hourglass architecture gives a significant boost to the quality of the prediction, even with a smaller number of parameters.

MediaPipe Pose is the ML solution for high-fidelity body pose tracking, inferring 33 2D and 3D (Dimension) landmarks, and background segmentation mask on the whole body from RGB video frames by utilizing the BlazePose. The current state-of-the-art approach for Pose Detection and Tracking relies on powerful desktop environments for processing, which consist of heavy GPUs and powerful CPUs. Whereas this Pose Detection method achieves real-time performance on most modern mobile phones, desktops/laptops, and even on the web only with CPU.

3.2 Model Architecture and Pipeline Design

3.2.1 Inference pipeline

For pose estimation, it utilizes a two-step detector-tracker ML pipeline. Using a detector, this pipeline first locates the pose region-of-interest (ROI) within the frame.

The tracker subsequently predicts all 33 pose key points from this ROI. Note that for video use cases, the detector is run only on the first frame. For subsequent frames, we derive the ROI from the previous frame's pose key points as discussed below (Fig. 3.5).

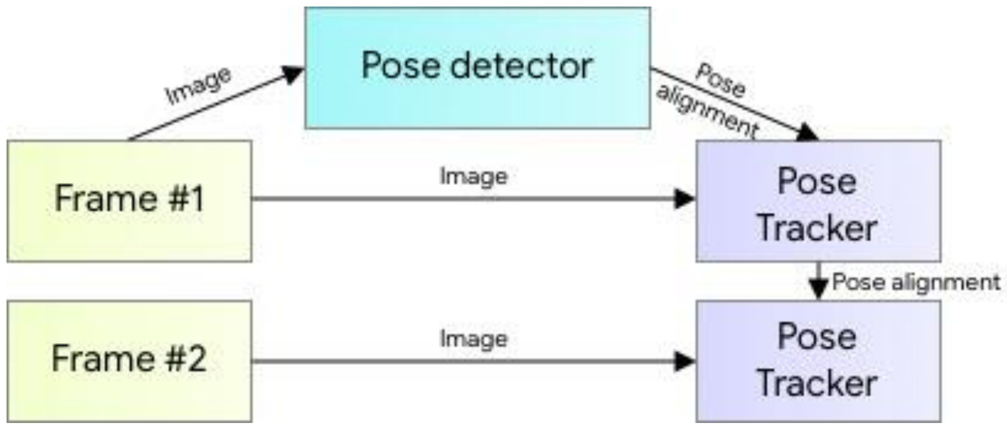


Fig. 3.5 Inference pipeline

3.2.2 Person detector

The majority of modern object detection solutions rely on the Non-Maximum Suppression (NMS) algorithm for their last post-processing step. This works well for rigid objects with few degrees of freedom. However, this algorithm breaks down for scenarios that include highly articulated poses like those of humans, e.g. people waving or hugging. This is because multiple, ambiguous boxes satisfy the intersection over union (IoU) threshold for the NMS algorithm.

To overcome this problem, the lightweight BlazeFace model, as a proxy for a pose detector. This model only detests the location of a person within the frame. It explicitly also predicts two additional virtual key points which then combined with Leonardo’s Vitruvian man to predict the midpoint of a person’s hips, the radius of a circle circumscribing the whole person, and the incline angle of the line connecting the shoulder and hip midpoints as shown below (Fig. 3.6).

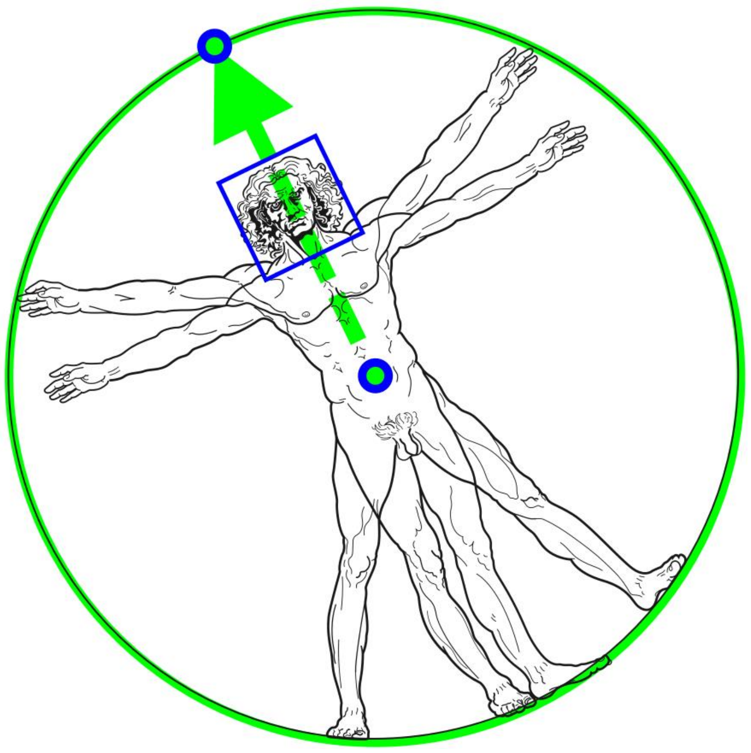
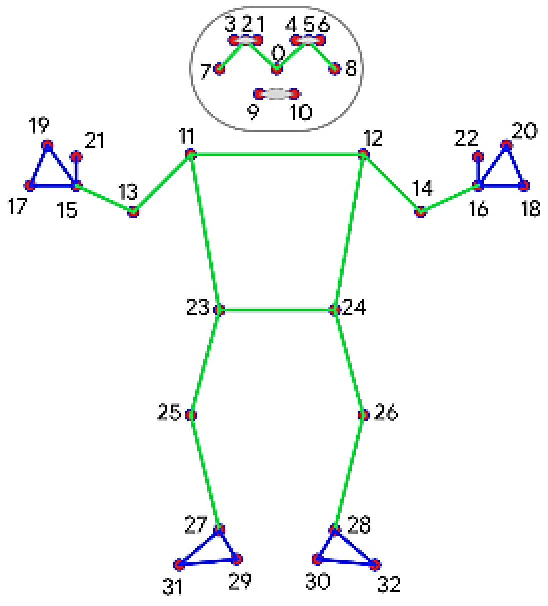


Fig. 3.6 Vitruvian man aligned via two virtual keypoints with face bounding box.

3.2.3 Topology

The current standard for human body pose is the COCO topology, which consists of 17 landmarks across the torso, arms, legs, and face. However, the COCO keypoints only localize to the ankle and wrist points, lacking scale and orientation information for hands and feet, which plays a vital role for practical applications like fitness and dance.

The inclusion of more key points is crucial for the subsequent application of domain-specific pose estimation models, like those for hands, face, or feet. With BlazePose, we can get 33 human body keypoints, which is a superset of COCO, BlazeFace, and BlazePalm topologies. This allows us to determine body semantics from pose prediction alone that is consistent with face and hand models (Fig. 3.7).



0.	nose	17.	right pinky knuckle #1
1.	right eye inner	18.	left pinky knuckle #1
2.	right eye	19.	right index knuclke #1
3.	right eye outer	20.	left index knuckle #1
4.	left eye inner	21.	right thumb knuckle #2
5.	left eye	22.	left thumb knuckle #2
6.	left eye outer	23.	right hip
7.	right ear	24.	left hip
8.	left ear	25.	right knee
9.	mouth right	26.	left knee
10.	mouth left	27.	right ankle
11.	right shoulder	28.	left ankle
12.	left shoulder	29.	right heel
13.	right elbow	30.	left heel
14.	left elbow	31.	right foot index
15.	right wrist	32.	left foot index
16.	left wrist		

Fig. 3.7 BlazePose 33 keypoints topology as COCO (coloured with green) superset

In this project, the COCO (Common Object in Context) dataset is used which is large-scale object detection, segmentation, and captioning dataset available publically that also includes the dataset of 250,000 people with body Key-points as shown in Fig(3.1). BlazePose used the COCO dataset as a base for further development and improvement in pose estimation. In this pose estimation, COCO is combined other two ML pipelines that are BlazeFace and BlazePalm to extend its application.

BlazeFace

The BlazeFace [17] model architecture is built around four important designs, which are following:

- Enlarging the receptive field size
- Feature extractor
- Anchor scheme
- Post-processing.

Enlarging the receptive field sizes: By modifying the convolutional neural network architectures tend which favour 3×3 convolution kernels.

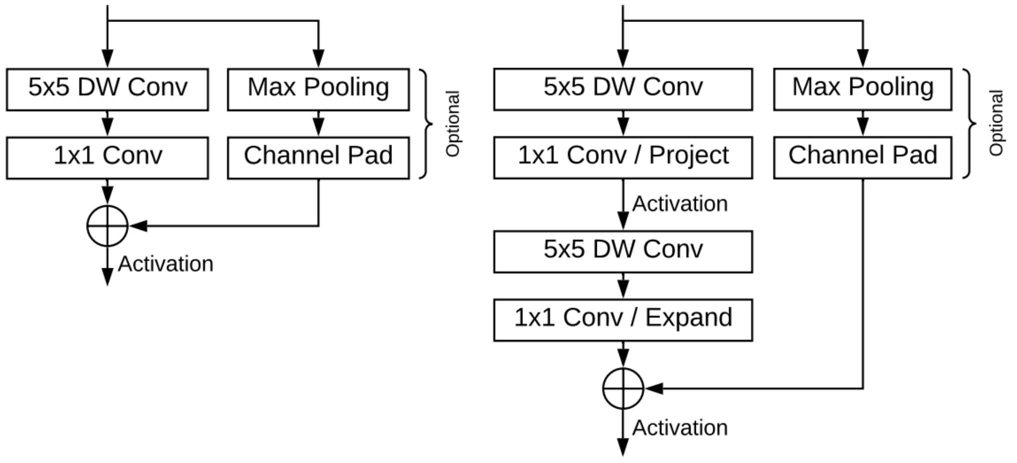


Fig. 3.8 BlazeBlock (left) and double BlazeBlock

For example, on an Apple iPhone X with the Metal Performance Shaders implementation [16], a 3×3 depthwise convolution in 16-bit floating-point arithmetic takes 0.07 ms for a 56×56×128 tensor, while the subsequent 1×1 convolution from 128 to 128 channels is 4.3 times slower at 0.3 ms. So increasing the kernel size of the depthwise part is relatively cheap. By employing 5×5 kernels in model architecture bottlenecks, trading the kernel size increase for the decrease in the total amount of such bottlenecks required to reach a particular receptive field size (Fig 3.8).

A MobileNetV2 bottleneck contains subsequent depth-increasing expansion and depth-decreasing projection pointwise convolutions separated by a non-linearity. To accommodate for the fewer number of channels in the intermediate tensors, by swapping these stages so that the residual connections in bottlenecks operate in the “expanded” (increased) channel resolution. This results in the low overhead of a depthwise convolution that allows introducing another layer between these two pointwise convolutions, accelerating the receptive field size progression even further. This forms the essence of a double BlazeBlock that is used as the bottleneck of choice for the higher abstraction level layers of BlazeFace (see Fig 3.8, right).

Feature extractor: For example, extracting the feature from the front-facing camera model. Which contains smaller object scales and therefore has lower computational demands. The extractor takes an RGB input of 128×128 pixels and consists of a 2D convolution followed by 5 single BlazeBlocks and 6 double BlazeBlocks (see Table in Annexer A for the full layout). The highest tensor depth (channel resolution) is 96, while the lowest spatial resolution is 8×8 (in contrast to SSD, which reduces the resolution down to 1×1).

Anchor scheme: A typical SSD model uses predictions from 1×1, 2×2, 4×4, 8×8, and 16×16 feature map sizes (Fig 3.9). However, the success of the Pooling Pyramid Network (PPN) architecture implies that additional computations could be redundant after reaching a certain feature map resolution. Taking this into consideration, by adopting an alternative anchor scheme that stops at the 8×8 feature map dimensions without further downsampling and replaced 2 anchors per pixel in each of the 8×8, 4×4 and 2×2 resolutions by 6 anchors at 8×8. Due to the limited variance in human face aspect ratios, limiting the anchors to the 1:1 aspect ratio is sufficient for accurate face detection.

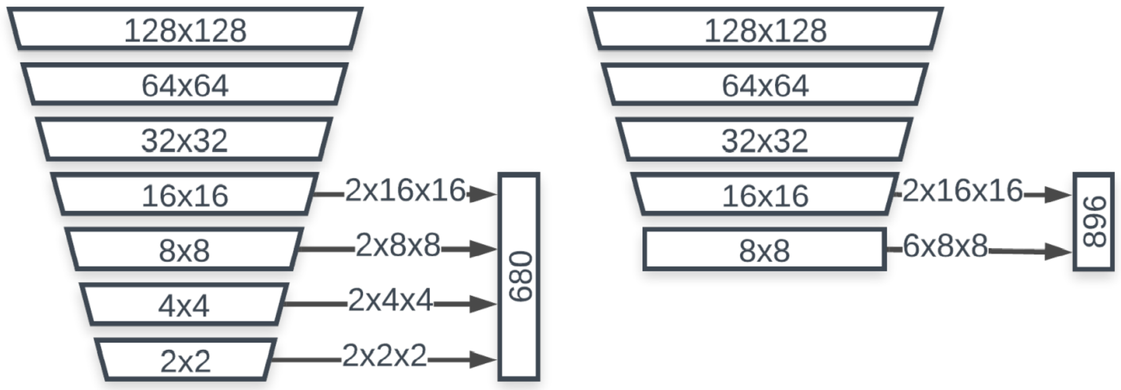


Fig. 3.9 Anchor computation: SSD (left) vs. BlazeFace

Post-processing: In this process, it increases the model accuracy and reduced the jittering problems as the feature extractor is not reducing the resolution below 8×8, the number of anchors overlapping a given object significantly increases with the object size and When such a model is applied to subsequent video frames, the predictions tend to fluctuate between different anchors and exhibit temporal jitter (human perceptible noise).

BlazePalm

The hand tracking solution utilizes an ML pipeline consisting of several models working together (Fig 3.10):

- A palm detector model operates on the full image and returns an oriented hand bounding box.
- A hand landmark model operates on the cropped image region defined by the palm detector and returns high fidelity 3D hand keypoints.

This architecture is similar to that employed face ML pipeline and that have used for pose estimation. Providing the accurately cropped palm image to the hand landmark model drastically reduces the need for data augmentation (e.g. rotations, translation and scale) and instead allows the network to dedicate most of its capacity towards coordinate prediction accuracy.

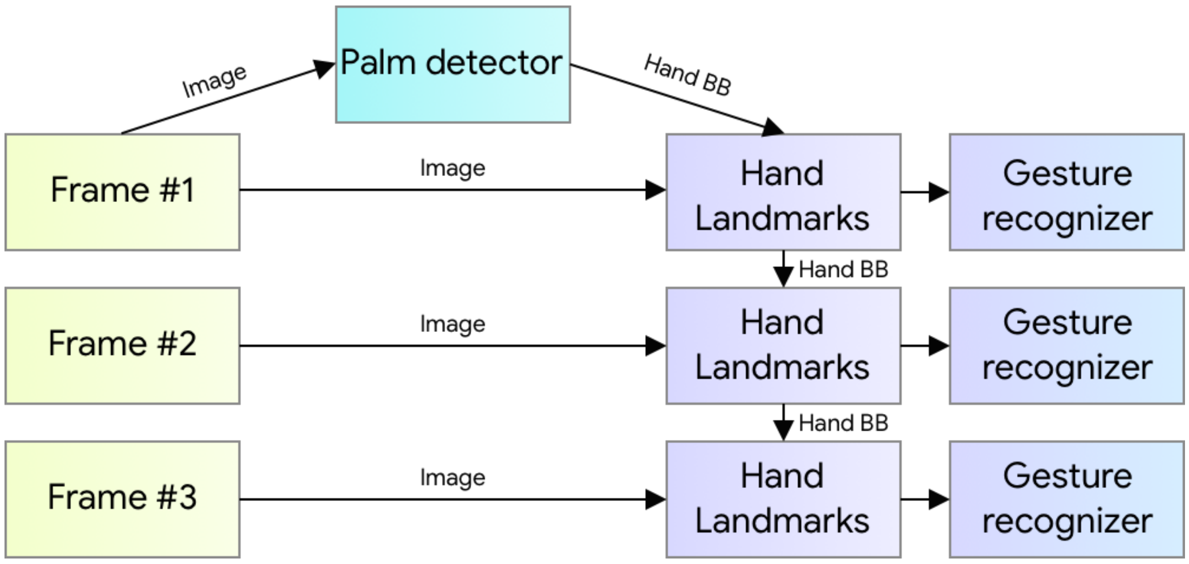


Fig. 3.10 Hand perception pipeline

3.2.4 Neural network architecture

The pose estimation component of the pipeline predicts the location of all 33 key points of a person with three degrees of freedom each (*x, y* location and visibility) plus the two virtual alignment key points described above.

Unlike current approaches that employ compute-intensive heatmap prediction to detect or extract key points from an image or a video frame, whereas this model uses a regression approach that is supervised by a combined heat map/offset prediction of all key points, as shown below (Fig. 3.11).

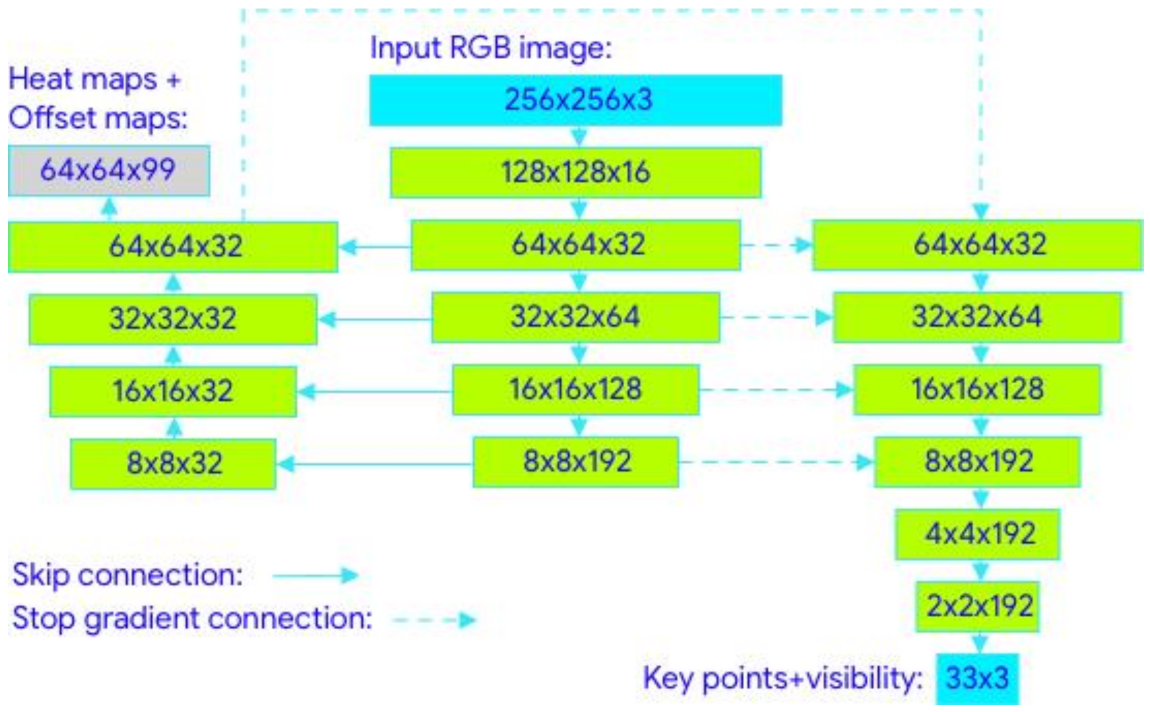


Fig. 3.11 Network architecture: regression with heatmap supervision.

Specifically, during training first, employ a heatmap and offset the loss to train the centre and left tower of the network. Then remove the heatmap output and train the regression encoder (right tower), thus, effectively using the heatmap to supervise a lightweight embedding.

The below table shows the result that is achieved by this process from different training strategies. As an evaluation metric, use the Percent of Correct Points with 20% tolerance (PCK@0.2) if the 2D Euclidean error is smaller than 20% of the corresponding person's torso size.

Table 3.1 Model quality resulting

	Mean 2D Euclidean error, normalized by torso size	*PCK@0.2*
Heatmaps	16.2	83.6
Regression without Heatmap loss	15.9	79.9
Regression with Heatmap regularization	**14.4**	**84.1**

To cover a wide range of hardware compatibility, they provide three pose tracking models: lite, full and heavy, which have different complexity differentiated in the balance of speed versus quality. For performance evaluation on CPU, they use XNNPACK which is a highly optimized library of floating-point neural network inference operators for ARM, Web Assembly, and x86 platforms. It is not intended for direct use by deep learning practitioners and researchers; instead, it provides low-level performance primitives for accelerating high-level machine learning frameworks, such as Tensor Flow Lite, TensorFlow.js, PyTorch, and MediaPipe. And for mobile GPUs, we can use the TFLite GPU backend, which is specifically designed for Mobile use and it use hardware accelerators provided by different operating system such as Android (requires OpenCL or OpenGL ES 3.1 and higher) and iOS (requires iOS 8 or later).

Table 3.2 FPS Results

	Pixel 3 CPU FPS using XNNPACK	*Pixel 3 CPU FPS using TFLite GPU*	*Ryzen 7 CPU using XNNPACK*
BlazePose lite	44	49	35
BlazePose full	18	40	21
BlazePose heavy	4	19	7

CHAPTER 4: DRONE & POSE FUSION

In this section, we are going to implement all the knowledge that we gain in the above chapters to develop the main application. Moreover, this section also helps or allows anybody who doesn't have any prior knowledge of the Tello drone, to perform simple missions by using Python script.

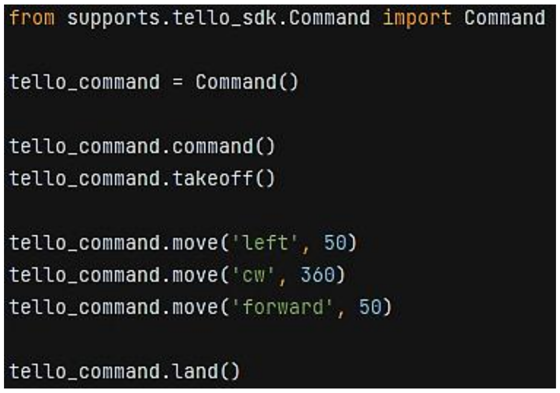
After that, we move further to integrate Pose recognition to control the drone and to perform various by using body movements.

4.1. Introduction to Tello Programming

Tello Python script which has been used in this project is provided on GitHub [1]. But you can use DjiTellopy [2] SDK also.

4.1.1 Simple Maneuver

The first step is importing all the classes, then connecting the drone Wi-Fi with a computer to provide commands through a Python script. We will initialize a few objects and parameters, then commands are sent to the drone. In this simple flight, first, we take off then move left, rotate clockwise, move forward and land.



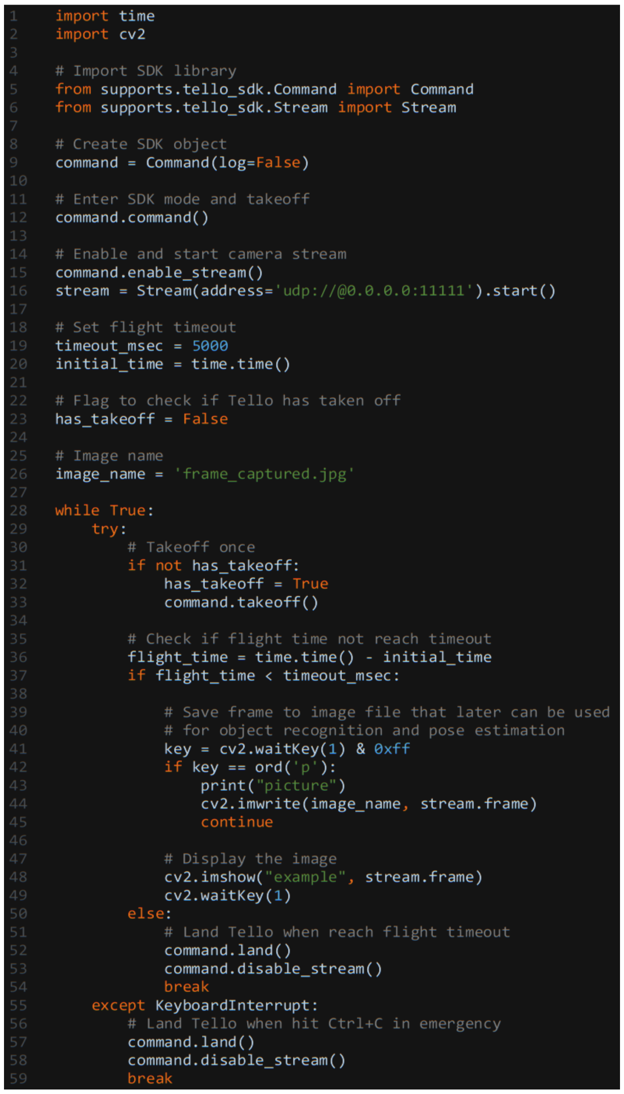
```
from supports.tello_sdk.Command import Command

tello_command = Command()

tello_command.command()
tello_command.takeoff()

tello_command.move('left', 50)
tello_command.move('cw', 360)
tello_command.move('forward', 50)

tello_command.land()
```

Fig. 4.1 Simple Python Script.

In the above script when we create the object of Command class names as "tello_command", but you can use any name you want and initialize the command function. Then we sent takeoff, move and land commands by using their function.

4.1.2 Simple Take Picture

Now, in the second script, we will initialize the Drone cam and capture a picture and save it in the drive.



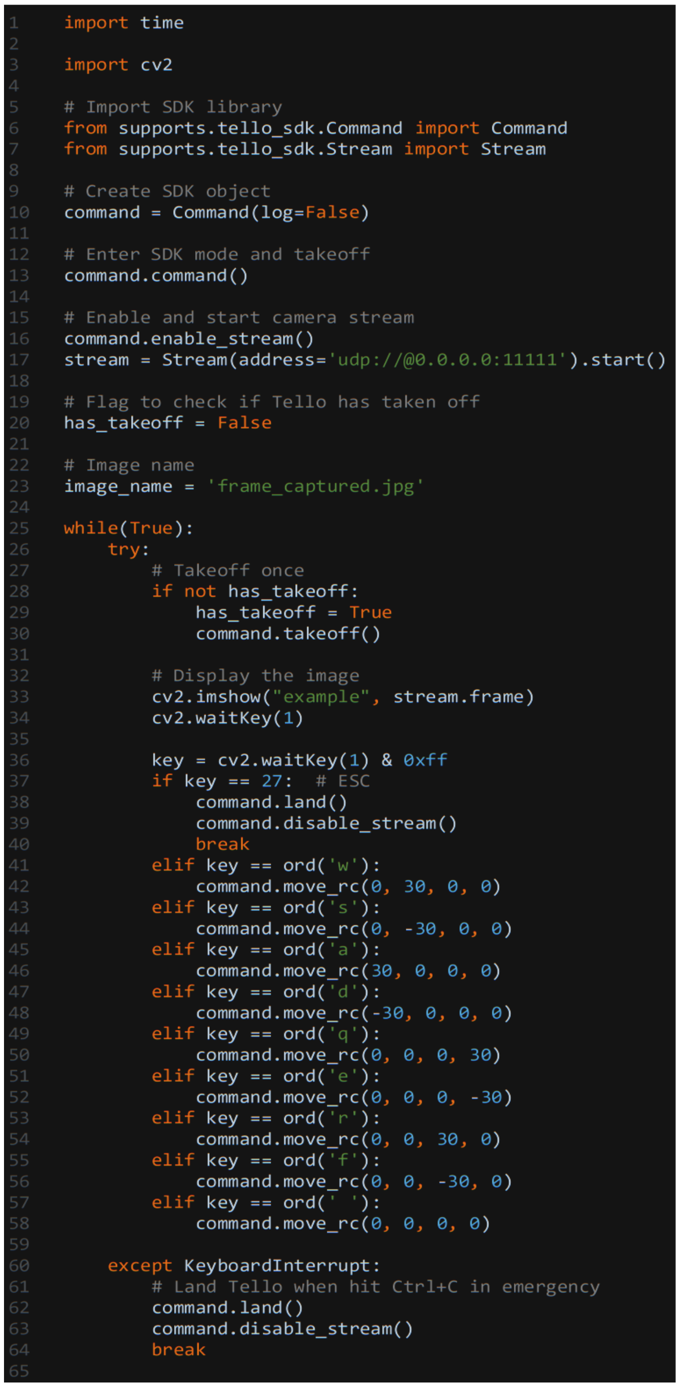
```python
import time
import cv2

# Import SDK library
from supports.tello_sdk.Command import Command
from supports.tello_sdk.Stream import Stream

# Create SDK object
command = Command(log=False)

# Enter SDK mode and takeoff
command.command()

# Enable and start camera stream
command.enable_stream()
stream = Stream(address='udp://@0.0.0.0:11111').start()

# Set flight timeout
timeout_msec = 5000
initial_time = time.time()

# Flag to check if Tello has taken off
has_takeoff = False

# Image name
image_name = 'frame_captured.jpg'

while True:
    try:
        # Takeoff once
        if not has_takeoff:
            has_takeoff = True
            command.takeoff()

        # Check if flight time not reach timeout
        flight_time = time.time() - initial_time
        if flight_time < timeout_msec:

            # Save frame to image file that later can be used
            # for object recognition and pose estimation
            key = cv2.waitKey(1) & 0xff
            if key == ord('p'):
                print("picture")
                cv2.imwrite(image_name, stream.frame)
                continue

            # Display the image
            cv2.imshow("example", stream.frame)
            cv2.waitKey(1)
        else:
            # Land Tello when reach flight timeout
            command.land()
            command.disable_stream()
            break
    except KeyboardInterrupt:
        # Land Tello when hit Ctrl+C in emergency
        command.land()
        command.disable_stream()
        break
```

Fig. 4.2 Take Picture Python Script.

So, the initialization is the same. But this time we import the cv2 and Stream class and initialize the steaming address. Then we take off and enable the stream. After, that we read the frame from the live feed of the drone camera and save the frame as “frame.jpg” into the drive and land the drone.

4.1.3 Manual Control

This python script is a simple demonstration to control the Tell drone using Keyboard.



```python
import time

import cv2

# Import SDK library
from supports.tello_sdk.Command import Command
from supports.tello_sdk.Stream import Stream

# Create SDK object
command = Command(log=False)

# Enter SDK mode and takeoff
command.command()

# Enable and start camera stream
command.enable_stream()
stream = Stream(address='udp://@0.0.0.0:11111').start()

# Flag to check if Tello has taken off
has_takeoff = False

# Image name
image_name = 'frame_captured.jpg'

while(True):
    try:
        # Takeoff once
        if not has_takeoff:
            has_takeoff = True
            command.takeoff()

        # Display the image
        cv2.imshow("example", stream.frame)
        cv2.waitKey(1)

        key = cv2.waitKey(1) & 0xff
        if key == 27:  # ESC
            command.land()
            command.disable_stream()
            break
        elif key == ord('w'):
            command.move_rc(0, 30, 0, 0)
        elif key == ord('s'):
            command.move_rc(0, -30, 0, 0)
        elif key == ord('a'):
            command.move_rc(30, 0, 0, 0)
        elif key == ord('d'):
            command.move_rc(-30, 0, 0, 0)
        elif key == ord('q'):
            command.move_rc(0, 0, 0, 30)
        elif key == ord('e'):
            command.move_rc(0, 0, 0, -30)
        elif key == ord('r'):
            command.move_rc(0, 0, 30, 0)
        elif key == ord('f'):
            command.move_rc(0, 0, -30, 0)
        elif key == ord(' '):
            command.move_rc(0, 0, 0, 0)

    except KeyboardInterrupt:
        # Land Tello when hit Ctrl+C in emergency
        command.land()
        command.disable_stream()
        break

```

Fig. 4.3 Manual control Python Script.

We use W, S, A, D keys for moving Forward, Backward, Left, Right; E, Q keys for rotation and R, F keys for moving Up and Down; To stop movement press the spacebar. When the script starts Tello will take off automatically and for landing and to terminate the script press ESC (Escape) key. To know more commands regarding Tello download its SDK [1]. And these and some more examples are also available in the example folder of Tello SDK [2].

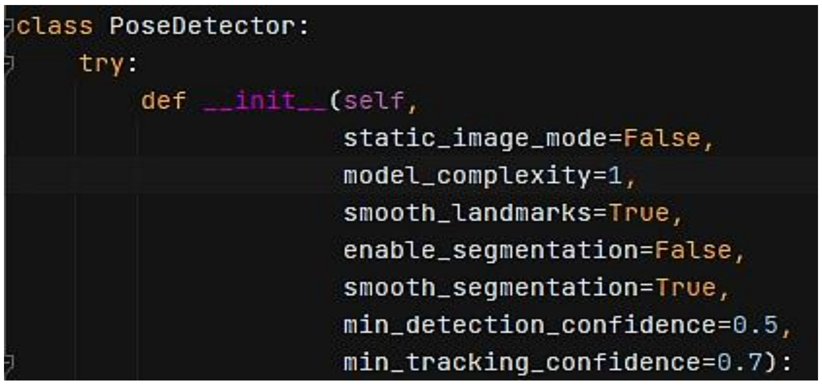
4.2. Pose Class

I have created a custom object-oriented Pose Class for this project in python language, which include all the necessary functions that we are going to use in this project. Those who have little knowledge of coding can be able to under the programming easily as everything is commented on and explained well. In this section, we will learn in more depth about Pose Detection.

4.2.1 Introduction to Class

The Pose Class contain various function like find_body, find angle, centroid, distance b/w two points and pose classification which we discuss in brief in this section one by one.

First of all, we need to import MediaPipe and some other python libraries to start with like python OpenCV, math etc. Then we create an object-oriented Pose Detector class, in which we create some Constructors. Constructors are used to initializing the object's state and the task of constructors is to initialize (assign values) to the data members of the class when an object of a class is created and it's run as soon as an object of a class is instantiated.

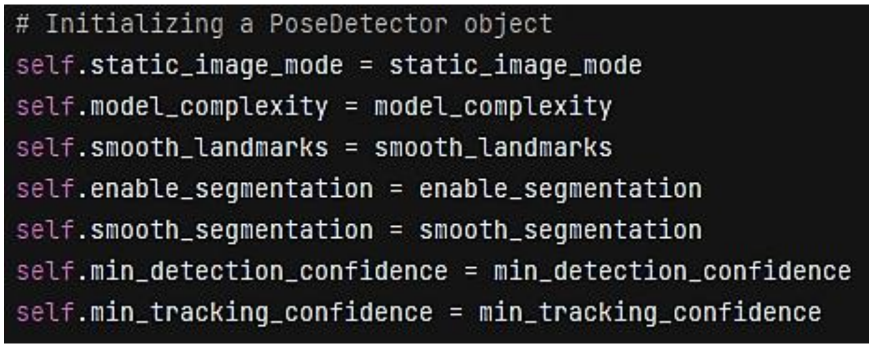


```
class PoseDetector:
    try:
        def __init__(self,
                     static_image_mode=False,
                     model_complexity=1,
                     smooth_landmarks=True,
                     enable_segmentation=False,
                     smooth_segmentation=True,
                     min_detection_confidence=0.5,
                     min_tracking_confidence=0.7):
```

Fig. 4.4 Pose Detector class constructor.

Here we use the __init__ function as a constructor, or initializer and is automatically called when we create a new instance of a class. Within that function, the newly created object is assigned to the parameter 'self.' and their default values (Fig 4.4).

The notation "self.static_image_mode" (Fig 4.5) are an attribute called Static_image_mode of the object in the variable self. In this function we initialize the MediaPipe Pose objects as shown below:



```
# Initializing a PoseDetector object
self.static_image_mode = static_image_mode
self.model_complexity = model_complexity
self.smooth_landmarks = smooth_landmarks
self.enable_segmentation = enable_segmentation
self.smooth_segmentation = smooth_segmentation
self.min_detection_confidence = min_detection_confidence
self.min_tracking_confidence = min_tracking_confidence
```

Fig. 4.5 Pose Detector class objects.

Where Arguments used in the MediaPipe are explained below:

STATIC_IMAGE_MODE

If set to false, the solution treats the input images as a video stream. It will try to detect the most prominent person in the very first images, and upon a successful detection further localizes the pose landmarks. In subsequent images, it then simply tracks those landmarks without invoking another detection until it loses track, reducing computation and latency. If set to true, person detection runs every input image, ideal for processing a batch of static, possibly unrelated, images. Default to false.

MODEL_COMPLEXITY

The complexity of the pose landmark model: 0, 1 or 2. Landmark accuracy, as well as inference latency, generally go up with the model complexity. Default to 1.

SMOOTH_LANDMARKS

If set to true, the solution filters pose landmarks across different input images to reduce jitter but ignored if static_image_mode is also set to true. Default to true.

ENABLE_SEGMENTATION

If set to true, in addition to the pose landmarks the solution also generates the segmentation mask. Default to false.

SMOOTH_SEGMENTATION

If set to true, the solution filters segmentation masks across different input images to reduce jitter. Ignored if enable_segmentation is false or static_image_mode is true. Default to true.

MIN_DETECTION_CONFIDENCE

Minimum confidence value ([0.0, 1.0]) from the person-detection model for the detection to be considered successful. Default to 0.5.

MIN_TRACKING_CONFIDENCE

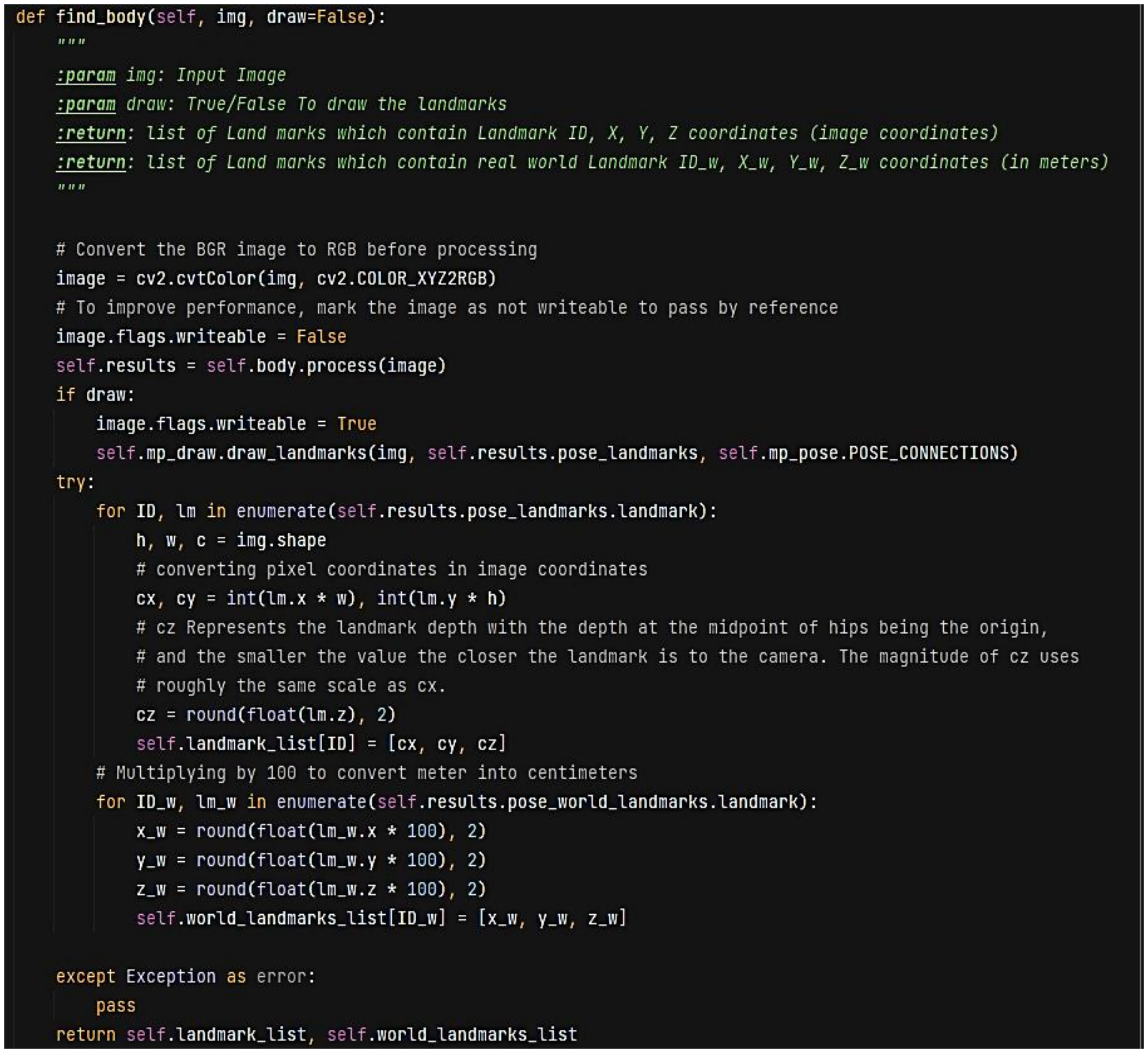
Minimum confidence value ([0.0, 1.0]) from the landmark-tracking model for the pose landmarks to be considered tracked successfully, or otherwise person detection will be invoked automatically on the next input image. Setting it to a higher value can increase the robustness of the solution, at the expense of higher latency. Ignored if static_image_mode is true, where person detection simply runs on every image. Default to 0.5.

4.2.2 Introduction to Functions

This section is dedicated to various functions in the class and their explanation.

FIND_BODY FUNCTION

This function is the main function that finds the Person/Pose in the frame and draws the pose. The input for the function is only the image or frames of the video for which we want to find the pose and you also can enable/disable the draw option by the Boolean input by setting up the draw True/False.



```python
def find_body(self, img, draw=False):
    """
    :param img: Input Image
    :param draw: True/False To draw the landmarks
    :return: list of Land marks which contain Landmark ID, X, Y, Z coordinates (image coordinates)
    :return: list of Land marks which contain real world Landmark ID_w, X_w, Y_w, Z_w coordinates (in meters)
    """

    # Convert the BGR image to RGB before processing
    image = cv2.cvtColor(img, cv2.COLOR_XYZ2RGB)
    # To improve performance, mark the image as not writeable to pass by reference
    image.flags.writeable = False
    self.results = self.body.process(image)
    if draw:
        image.flags.writeable = True
        self.mp_draw.draw_landmarks(img, self.results.pose_landmarks, self.mp_pose.POSE_CONNECTIONS)
    try:
        for ID, lm in enumerate(self.results.pose_landmarks.landmark):
            h, w, c = img.shape
            # converting pixel coordinates in image coordinates
            cx, cy = int(lm.x * w), int(lm.y * h)
            # cz Represents the landmark depth with the depth at the midpoint of hips being the origin,
            # and the smaller the value the closer the landmark is to the camera. The magnitude of cz uses
            # roughly the same scale as cx.
            cz = round(float(lm.z), 2)
            self.landmark_list[ID] = [cx, cy, cz]
        # Multiplying by 100 to convert meter into centimeters
        for ID_w, lm_w in enumerate(self.results.pose_world_landmarks.landmark):
            x_w = round(float(lm_w.x * 100), 2)
            y_w = round(float(lm_w.y * 100), 2)
            z_w = round(float(lm_w.z * 100), 2)
            self.world_landmarks_list[ID_w] = [x_w, y_w, z_w]

    except Exception as error:
        pass
    return self.landmark_list, self.world_landmarks_list
```

Fig. 4.6 Find body function.

The outputs or return value of this function are:

<u>Landmarks list:</u>

A list of pose landmarks. Each landmark consists of the following:

- x and y: Landmark coordinates normalized to [0.0, 1.0] by the image width and height respectively.[1]

[1] Converted into Pixel Co-ordinates

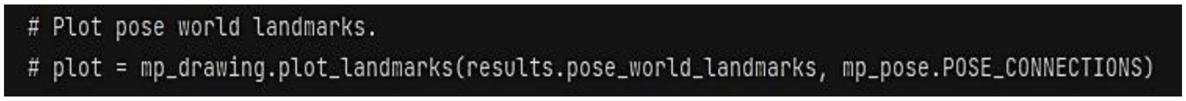
- z: Represents the landmark depth with the depth at the midpoint of hips being the origin, and the smaller the value the closer the landmark is to the camera. The magnitude of z uses roughly the same scale as x.

World landmarks list:

Another list of pose landmarks in world coordinates. Each landmark consists of the following:

- x, y and z: Real-world 3D coordinates in centimetres with the origin at the centre between hips.

To draw the plot, we need to call the internal function of MediaPipe class. You can find the code for this in my GitHub repository [3], under the example folder in simple_example.py I put in the comment but if you want to plot or see the result you can uncomment this line as shown below (Fig. 4.7).



```
# Plot pose world landmarks.
# plot = mp_drawing.plot_landmarks(results.pose_world_landmarks, mp_pose.POSE_CONNECTIONS)
```

Fig. 4.7 Plot function.

An example of a landmarks list and world landmarks list is plotted in Real-world 3D coordinates is shown in the figure below (Fig 4.8), this plots which shown in figure (Fig 4.8) are the plots of a static image, but it can also be plotted for video in real-time. In the figure (Fig 4.8) the plots of the world landmark list from the different viewing angles and the scale of the plots in X, Y, Z axis are in meters.

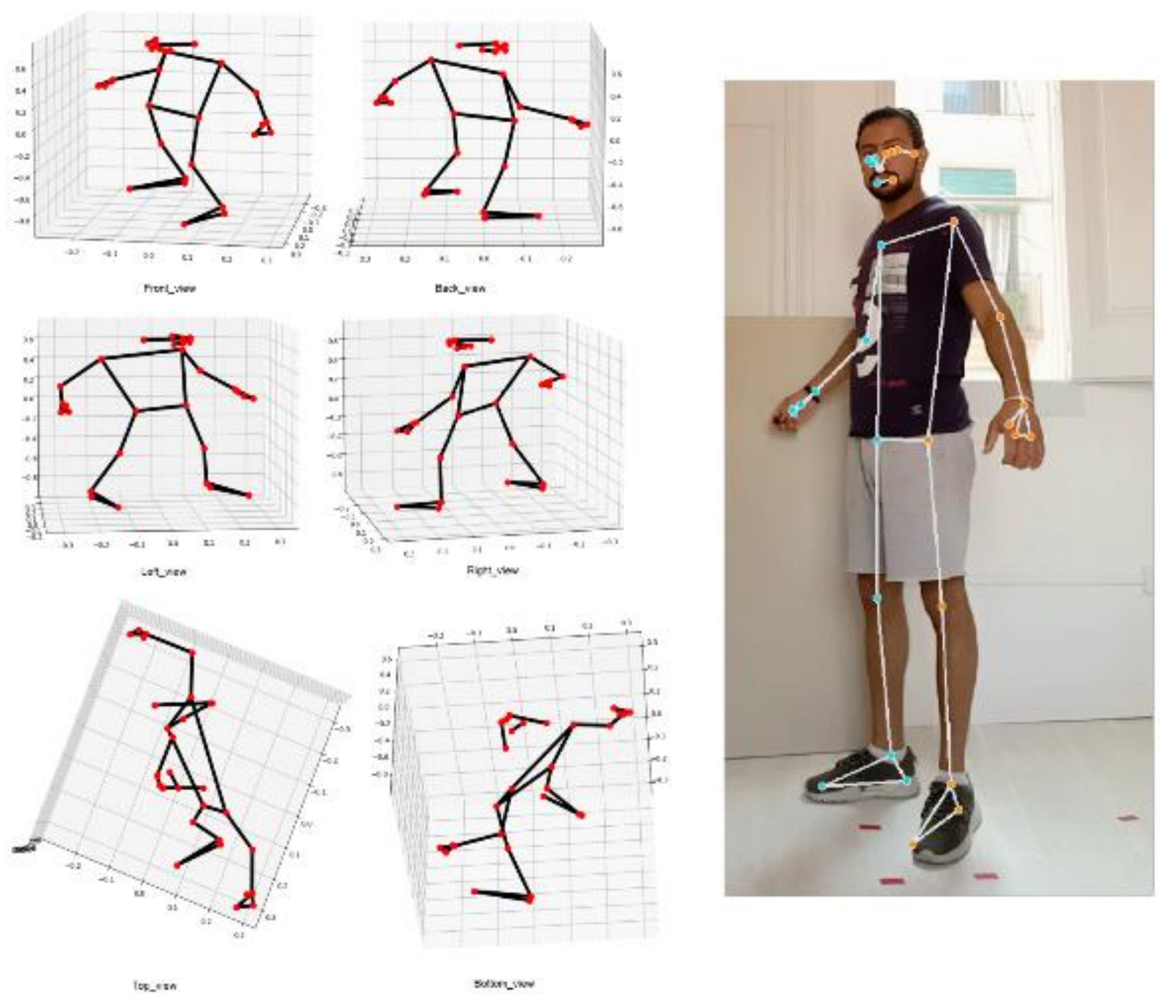
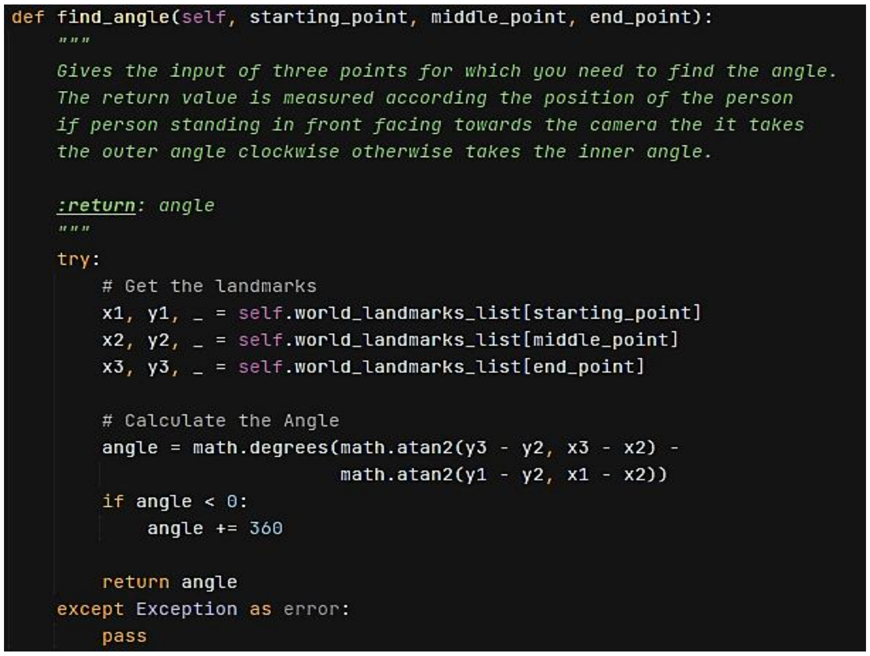


Fig. 4.8 Real-world 3D coordinates.

FIND ANGLE FUNCTION

This function uses the world coordinates to calculate the angle between any three body landmarks and the returns value is measured according to the position of the person; if the person standing in front facing towards the camera then it takes the outer angle clockwise otherwise takes the inner angle. Function python script (Fig. 4.9).

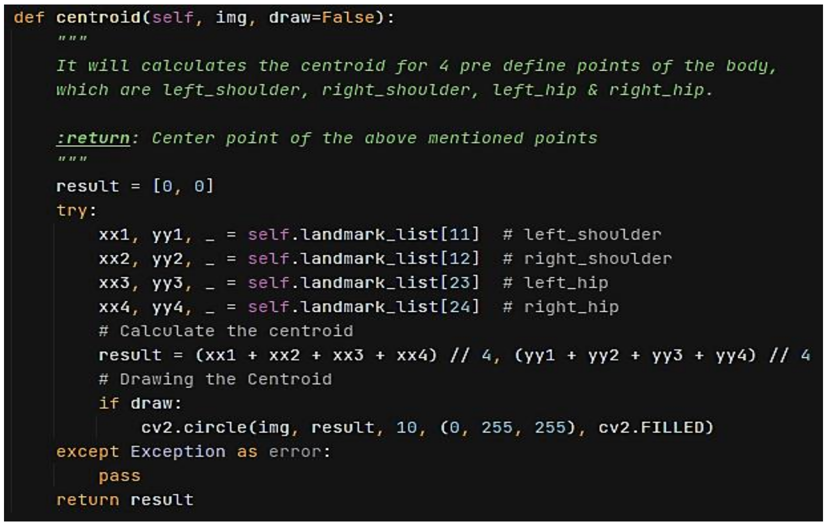


```python
def find_angle(self, starting_point, middle_point, end_point):
    """
    Gives the input of three points for which you need to find the angle.
    The return value is measured according the position of the person
    if person standing in front facing towards the camera the it takes
    the outer angle clockwise otherwise takes the inner angle.

    :return: angle
    """
    try:
        # Get the landmarks
        x1, y1, _ = self.world_landmarks_list[starting_point]
        x2, y2, _ = self.world_landmarks_list[middle_point]
        x3, y3, _ = self.world_landmarks_list[end_point]

        # Calculate the Angle
        angle = math.degrees(math.atan2(y3 - y2, x3 - x2) -
                             math.atan2(y1 - y2, x1 - x2))
        if angle < 0:
            angle += 360

        return angle
    except Exception as error:
        pass
```

Fig. 4.9 Angle between Pose Points.

CENTROID FUNCTION

This function calculates the centre of the upper body, which is four predefine points of the body i.e., left shoulder, right shoulder, left hip & right hip. The python script of the function is shown below (Fig. 4.10). You can also draw the centroid over the input image by just enabling or disabling the draw input value to True/False. This function further can be used for many other applications besides this project.

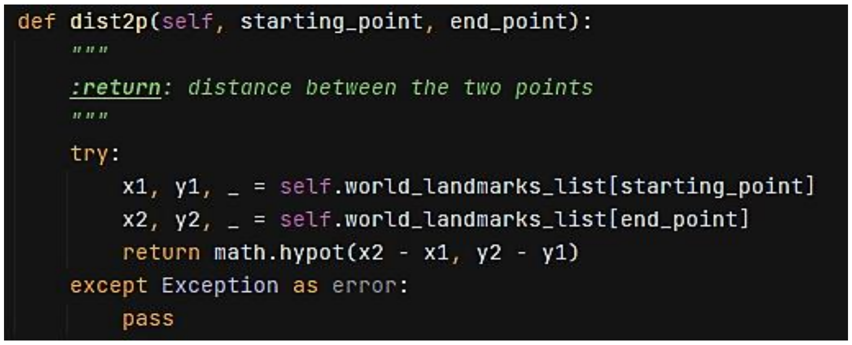


```python
def centroid(self, img, draw=False):
    """
    It will calculates the centroid for 4 pre define points of the body,
    which are left_shoulder, right_shoulder, left_hip & right_hip.

    :return: Center point of the above mentioned points
    """
    result = [0, 0]
    try:
        xx1, yy1, _ = self.landmark_list[11]  # left_shoulder
        xx2, yy2, _ = self.landmark_list[12]  # right_shoulder
        xx3, yy3, _ = self.landmark_list[23]  # left_hip
        xx4, yy4, _ = self.landmark_list[24]  # right_hip
        # Calculate the centroid
        result = (xx1 + xx2 + xx3 + xx4) // 4, (yy1 + yy2 + yy3 + yy4) // 4
        # Drawing the Centroid
        if draw:
            cv2.circle(img, result, 10, (0, 255, 255), cv2.FILLED)
    except Exception as error:
        pass
    return result
```

Fig. 4.9 Centroid Function

DISTANCE B/W TWO POINTS FUNCTION

This is a simple function that calculates the distance between two landmarks points and the distance in centimetres (Fig. 4.11).

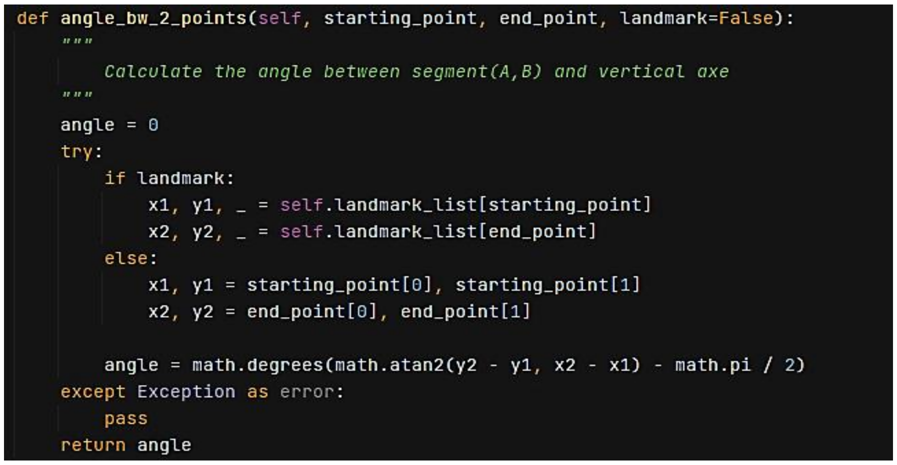


```python
def dist2p(self, starting_point, end_point):
    """
    :return: distance between the two points
    """
    try:
        x1, y1, _ = self.world_landmarks_list[starting_point]
        x2, y2, _ = self.world_landmarks_list[end_point]
        return math.hypot(x2 - x1, y2 - y1)
    except Exception as error:
        pass
```

Fig. 4.11 Distance Function

ANGLE B/W TWO POINTS FUNCTION

This function calculates the angle between two points in which the endpoint can be a landmark/body/pose point or it can be any manually defined point. This function allows extending the capability of the function to calculate the angle and increase the application pose class.

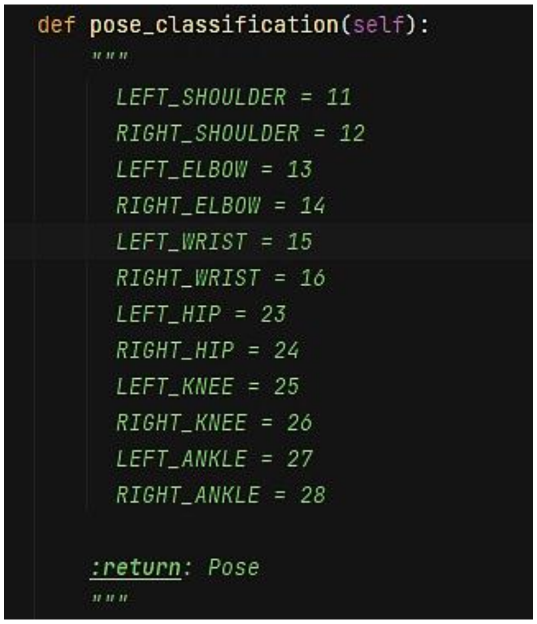


```python
def angle_bw_2_points(self, starting_point, end_point, landmark=False):
    """
        Calculate the angle between segment(A,B) and vertical axe
    """
    angle = 0
    try:
        if landmark:
            x1, y1, _ = self.landmark_list[starting_point]
            x2, y2, _ = self.landmark_list[end_point]
        else:
            x1, y1 = starting_point[0], starting_point[1]
            x2, y2 = end_point[0], end_point[1]

        angle = math.degrees(math.atan2(y2 - y1, x2 - x1) - math.pi / 2)
    except Exception as error:
        pass
    return angle
```

Fig. 4.12 Angle between Pose and World points

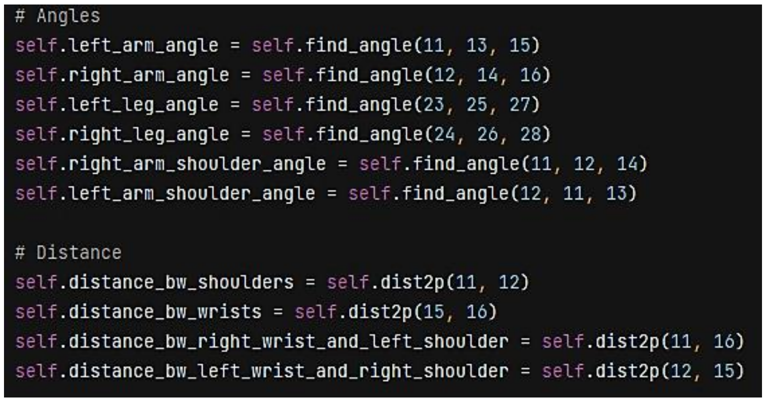
POSE CLASSIFICATION FUNCTION

This is the function that recognized the body pose with the help of previously defined functions. This means this function call the above-defined functions and then check the return value with previously defined bounds and classified the pose. The list of landmarks that I used to define pose, seen below (Fig. 4.13)



```
def pose_classification(self):
    """
      LEFT_SHOULDER = 11
      RIGHT_SHOULDER = 12
      LEFT_ELBOW = 13
      RIGHT_ELBOW = 14
      LEFT_WRIST = 15
      RIGHT_WRIST = 16
      LEFT_HIP = 23
      RIGHT_HIP = 24
      LEFT_KNEE = 25
      RIGHT_KNEE = 26
      LEFT_ANKLE = 27
      RIGHT_ANKLE = 28

    :return: Pose
    """
```

Fig. 4.13 Pose Landmarks



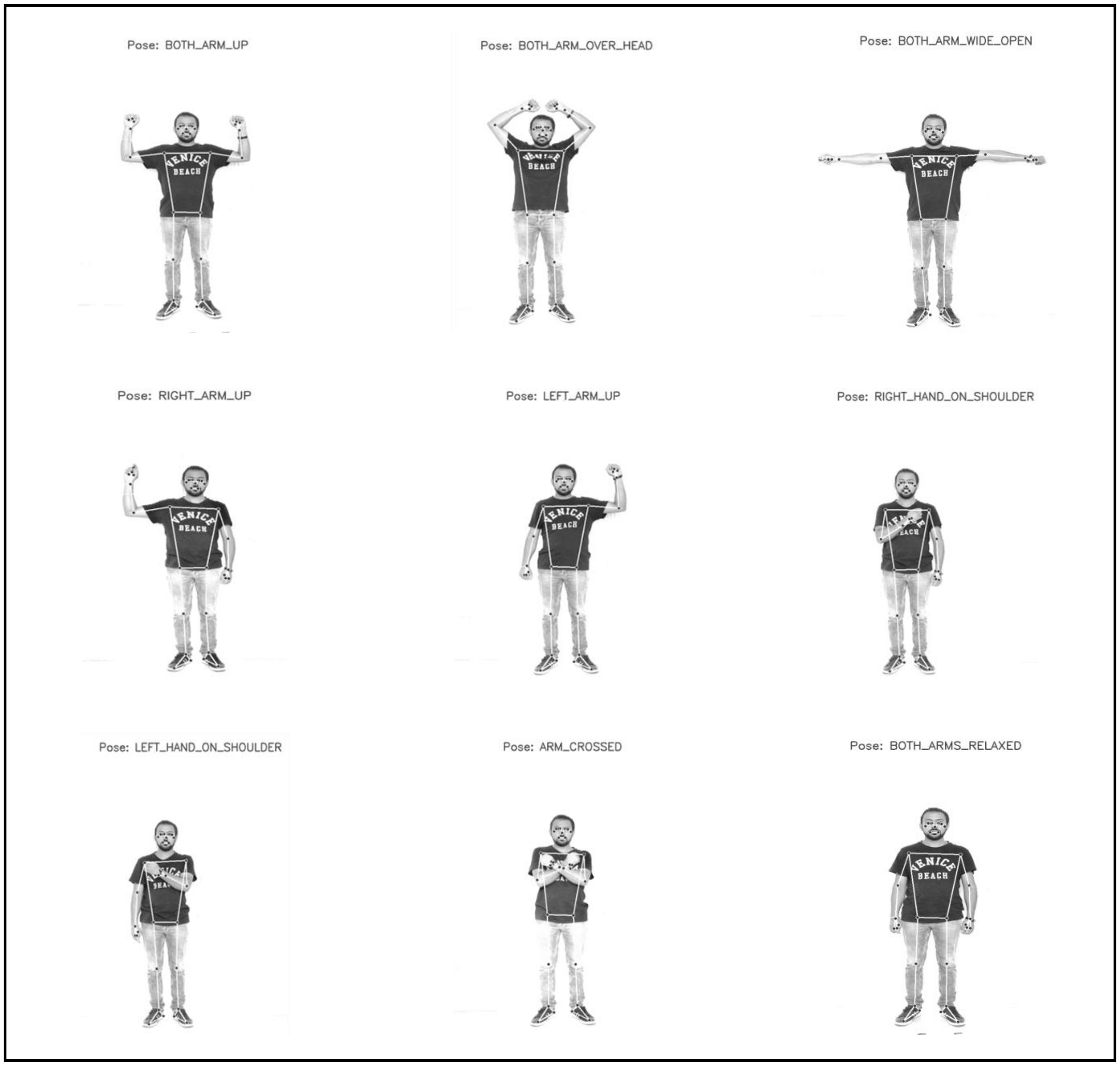
```
# Angles
self.left_arm_angle = self.find_angle(11, 13, 15)
self.right_arm_angle = self.find_angle(12, 14, 16)
self.left_leg_angle = self.find_angle(23, 25, 27)
self.right_leg_angle = self.find_angle(24, 26, 28)
self.right_arm_shoulder_angle = self.find_angle(11, 12, 14)
self.left_arm_shoulder_angle = self.find_angle(12, 11, 13)

# Distance
self.distance_bw_shoulders = self.dist2p(11, 12)
self.distance_bw_wrists = self.dist2p(15, 16)
self.distance_bw_right_wrist_and_left_shoulder = self.dist2p(11, 16)
self.distance_bw_left_wrist_and_right_shoulder = self.dist2p(12, 15)
```

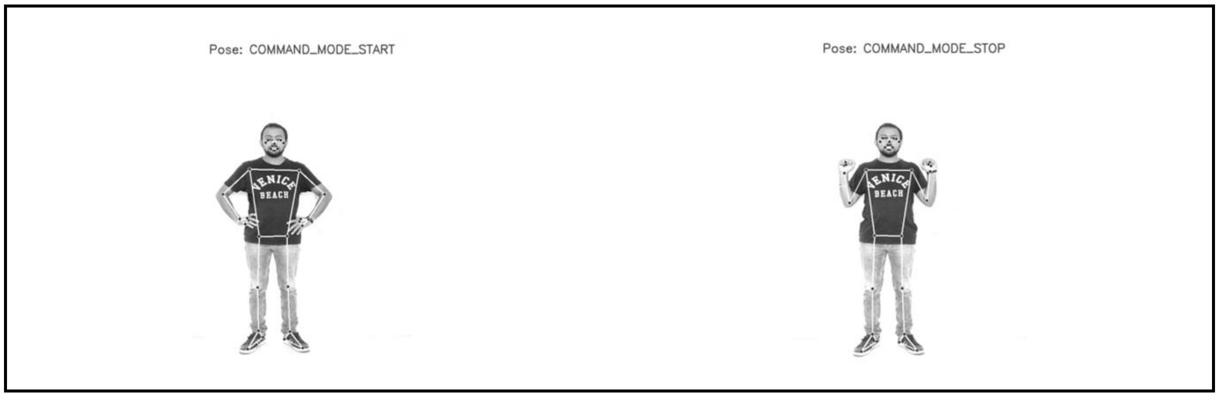
Fig. 4.14 Angle and Distance b/w Pose

By using the previously defined function we calculated and define various parameters, as shown above (Fig. 4.14). Now, by using values from these variables

We can define various poses as shown below (Table 4.1)

Table 4.1 Poses





4.3. Implementation

In this section, we are going to talk about the merging of our both classes. So, for merging both the Pose and Tello classes we are going to create a State Machine program that consists of different state functions and the main program to control all the processes of the state machine.

4.3.1 Introduction State Machine Diagram

This State machine diagram is typically used to explain our classes work. There are different states, objects and functions in our classes that act and behave differently depending on their current state. This state diagram will simply explain how everything is working in the first place. So, this state machine consists of 7 states with few conditions as shown below (Fig. 4.16).

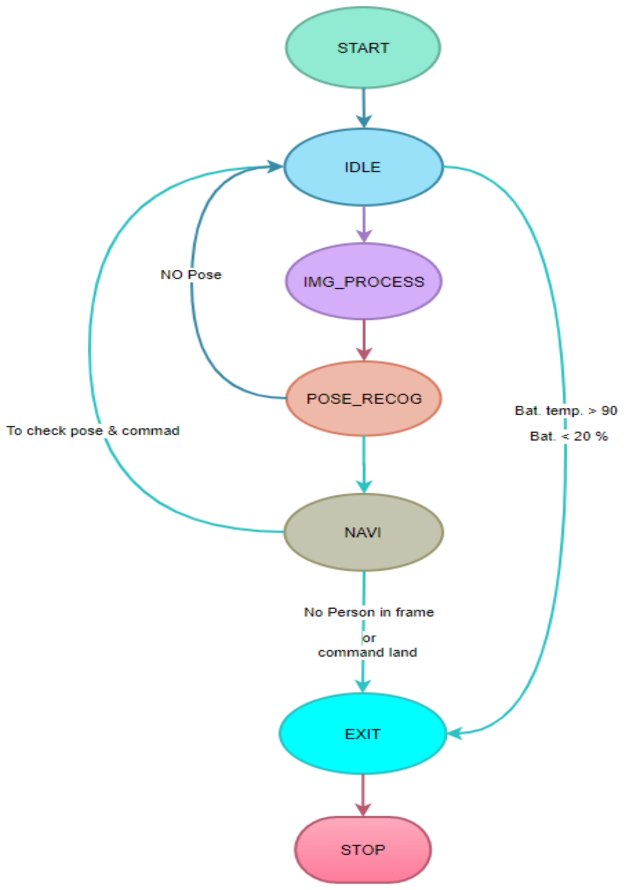
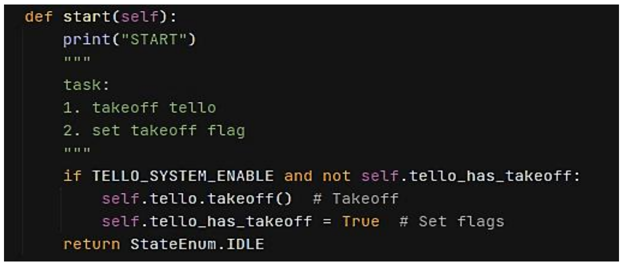


Fig. 4.15 State Machine

4.3.2 Explanation of State Machine

START

The "*Start*" state initiates the Tello takeoff command if the Tello system is connected and enabled. Then move to the next state as shown below (Fig. 4.16).

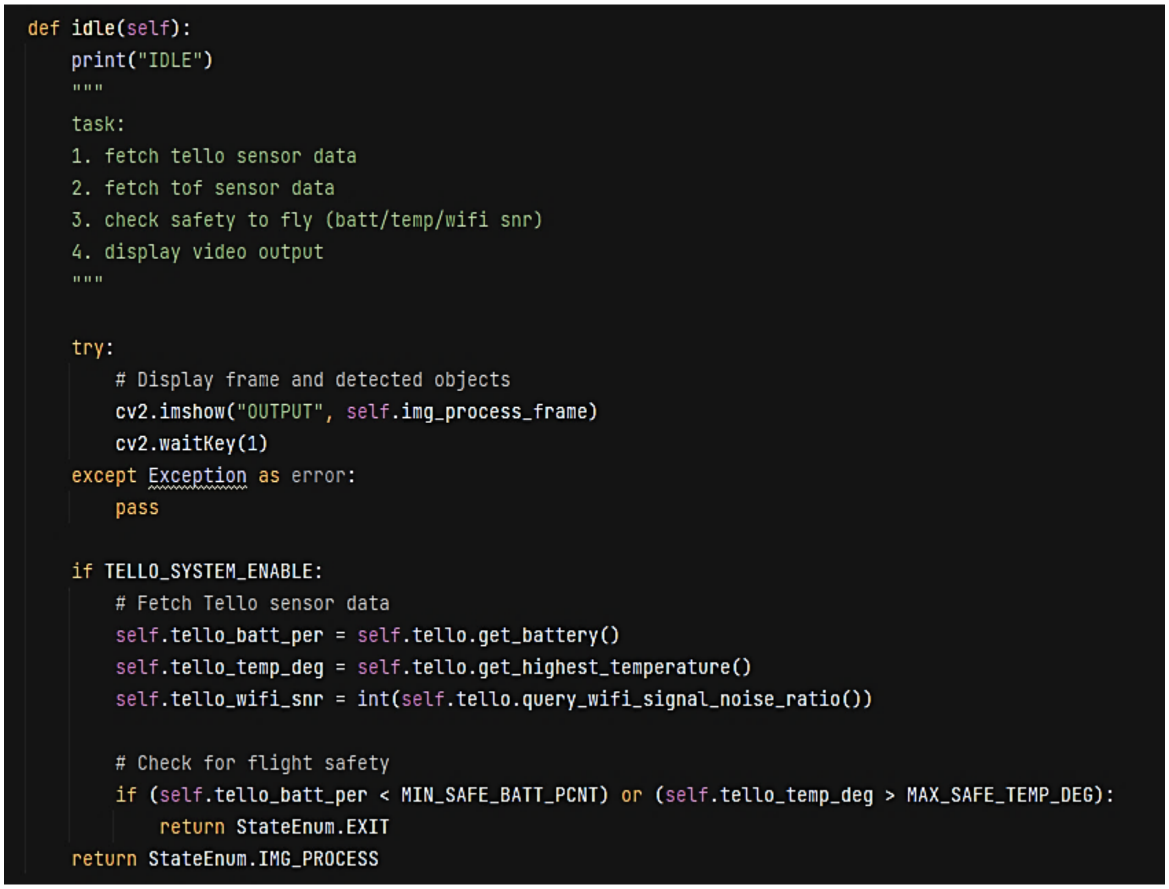


```
def start(self):
    print("START")
    """
    task:
    1. takeoff tello
    2. set takeoff flag
    """
    if TELLO_SYSTEM_ENABLE and not self.tello_has_takeoff:
        self.tello.takeoff()  # Takeoff
        self.tello_has_takeoff = True  # Set flags
    return StateEnum.IDLE
```

Fig. 4.16 Start state

IDLE

The “Idle” state fetches the Tello sensor data and displays the output image. Moreover, it also checks whether Tello is in a safe condition to fly or not by checking its battery temperature and how much battery percentage is left, as shown below (Fig. 4.17). If not then, its moves to the “Exit” state and initiate the landing command for Tello otherwise it moves to the next state “Img_Process”.

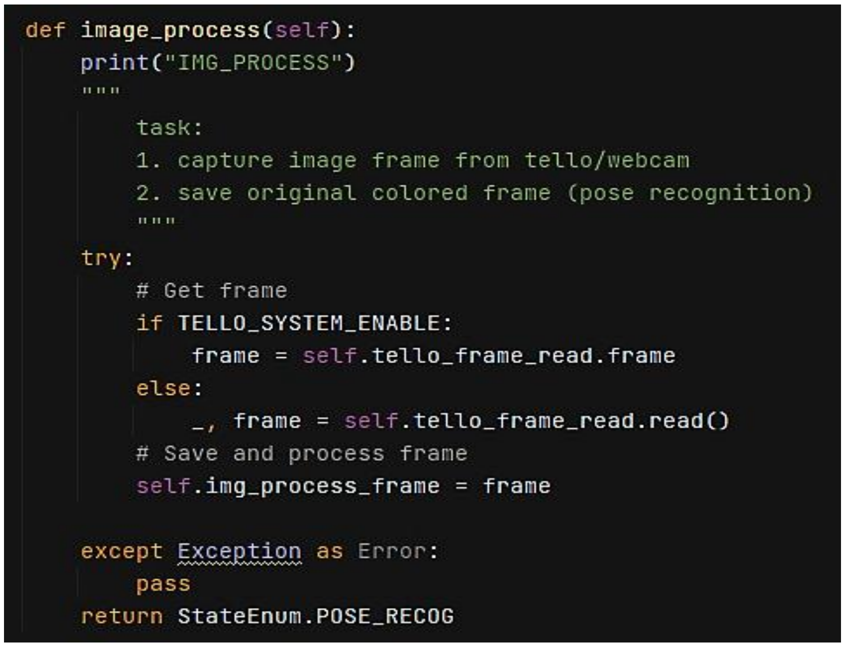


```python
def idle(self):
    print("IDLE")
    """
    task:
    1. fetch tello sensor data
    2. fetch tof sensor data
    3. check safety to fly (batt/temp/wifi snr)
    4. display video output
    """

    try:
        # Display frame and detected objects
        cv2.imshow("OUTPUT", self.img_process_frame)
        cv2.waitKey(1)
    except Exception as error:
        pass

    if TELLO_SYSTEM_ENABLE:
        # Fetch Tello sensor data
        self.tello_batt_per = self.tello.get_battery()
        self.tello_temp_deg = self.tello.get_highest_temperature()
        self.tello_wifi_snr = int(self.tello.query_wifi_signal_noise_ratio())

        # Check for flight safety
        if (self.tello_batt_per < MIN_SAFE_BATT_PCNT) or (self.tello_temp_deg > MAX_SAFE_TEMP_DEG):
            return StateEnum.EXIT
    return StateEnum.IMG_PROCESS
```

Fig. 4.17 Idle state

IMAGE PROCESS

The “Img_Process” state is used to read the video input frame by frame, the input video source can be streamed directly from a Tello cam or a webcam or prerecorded video. If the Tello system enables it will automatically read the Tello feed else the webcam or prerecorded video, and then it will proceed to the next state as shown below (Fig. 4.18).



```python
def image_process(self):
    print("IMG_PROCESS")
    """
        task:
        1. capture image frame from tello/webcam
        2. save original colored frame (pose recognition)
        """
    try:
        # Get frame
        if TELLO_SYSTEM_ENABLE:
            frame = self.tello_frame_read.frame
        else:
            _, frame = self.tello_frame_read.read()
        # Save and process frame
        self.img_process_frame = frame

    except Exception as Error:
        pass
    return StateEnum.POSE_RECOG
```

Fig. 4.18 Img_Process state

Now, we talk about the Pose Recognition and the Navigation States. These two states are the most important state of the program, as they do most of the process and work in the program. The code related to these two state functions is in **Annex B** below.

POSE RECOGNITION

The “pose_recognition” state as it is referred to by name it recognized the pose of the Human/Person. In this state function, two command modes, that helps to navigate the drone, depending upon a mode.

The first mode is tracking mode, which is an auto mode. When this mode is activated drone start tracking the person/human by maintaining a safe distance of approx. 3.5 meters and its move forward, backward, left and right as the person moves. It also manoeuvres forward, backward by the movement of the shoulders. For example, if you rotate/move your shoulder in the X-axis then the drone move forward and when your shoulder is parallel to the X-axis the drone goes to its position back.

The second Mode is the Command mode. In mode you can control the drone manually with the help of body gestures (as shown in Table 4.1), with different gestures drone can do different manoeuvres like up, down, left, right, forward and backward. You can also add more pose gestures according to your convenience.

NAVIGATION

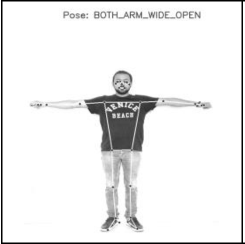
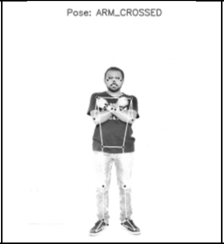
The “navigation”, as you know from its name this state function is responsible for the navigation of the drone in three dimensions space.

In this state function, we navigate the drone by calculating the PID for auto mode and taking commands for manual mode. But, before that drone is raised directly up to a certain height so that it can see or detect the whole body or person to recognize the pose. If it does not detect any for 20 seconds it will automatically land.

Auto Mode: Drone can be enabled in this Mode by using the “BOTH_ARM_WIDE_OPEN” pose (as shown in Table 4.2). After this mode enabled the drone to start aligning with the person centroid and when the alignment is completed, it starts following the person. If it does not detect any person in the frame then it starts searching the person by rotating on its axis, if it is still not able to detect the person then it will automatically go to the landing command for safety purposes.

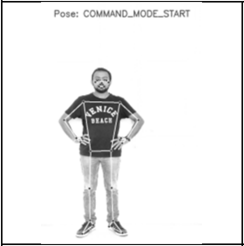
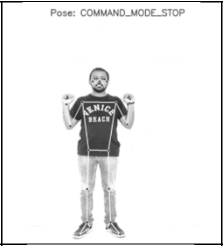
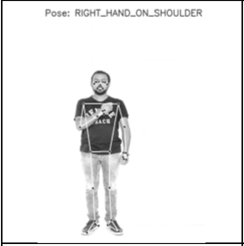
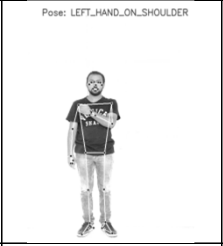
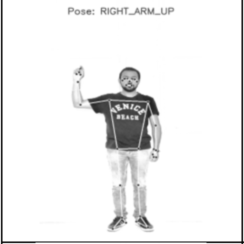
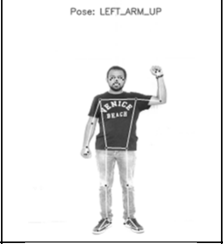
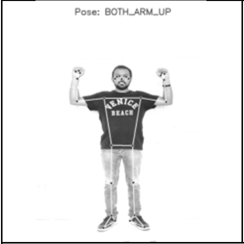
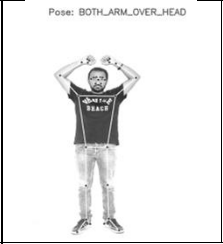
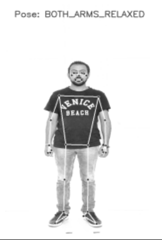
This mode can be deactivated/disabled by using the “ARM_CROSSED” pose (as shown in Table 4.2). It will come out of the auto mode and ready to accept another command.

Table 4.2 Pose Gestures for Auto Mode

Auto Mode			
	Tracking Start		Tracking Stop

Manual Mode: This mode can be activated by the “COMMAND_MODE_START” pose (as shown in Table 4.3). After that drone is ready to accept commands for the manoeuvre in three-dimensional space. Commands to control the drone manually are shown below in the table (Table 4.3).

Table 4.3 Different Pose Gestures Manual Mode

Manual Command Mode			
	Command Mode On		Command Mode Off Landing
	Forward		Backwards
	Right		Left
	Up		Down
		Stay at one position	

EXIT

This state function is used to come out from the state function for safety purposes and for landing the drone. This function is called several times during the programing for safety purposes or to execute the landing command. After this function, all function is terminated and STOP the code from executing further.

4.4. Main Application: Control the drone with Body Gestures

In this section, we want to continue with the progress made in the above sections, and import everything step by step.

4.4.1 Material Required

The component is used to perform all the tasks or manoeuvres:

- 1 X Tello or Tello EDU
- 1 X Laptop
- Wi-Fi Adapter or a Hotspot

4.4.2 Steps Required

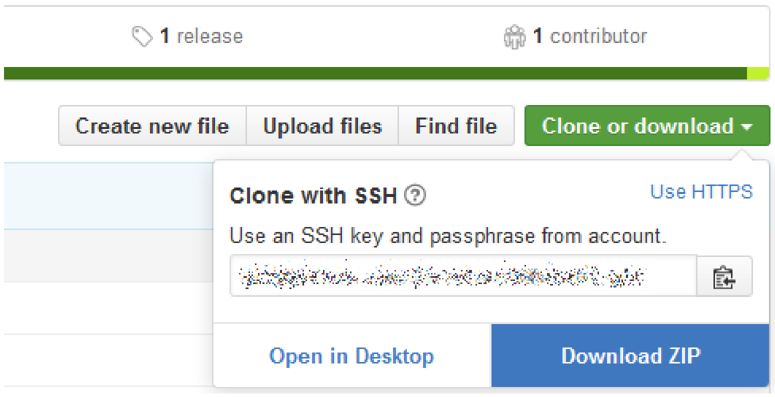
1. Get the repository from Github.

   i) By cloning for Ubuntu in Terminal (command line)

   Syntax:

```
git clone {repository URL}
```

   ii) By downloading the Zip file



Use an SSH key and passphrase from account.

2. Connect the laptop and the Drone to the same Wi-Fi Adapter or a Hotspot, to perform this application as shown in the figure below (Fig. 4.19).

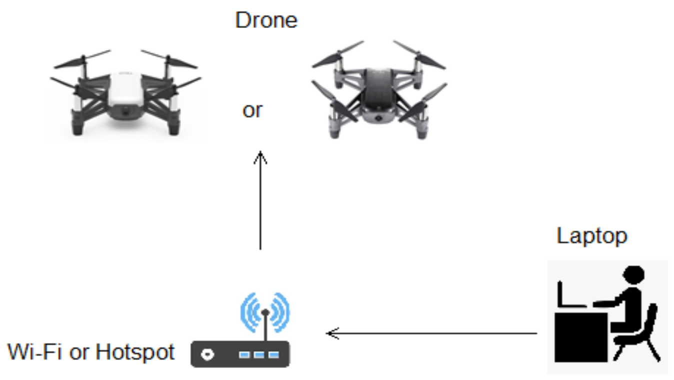


Fig. 4.19 Environmental Setup

3. Now check all the things are imported properly.

4. Now make the TELLO_SYSTEM_ENABLE = True, in the state.py to test the real-time application.

   OR

   Keep it False and test the program before running with the webcam.

4.4.3 Run and Play

After setting up the setup, you can run the program and enjoy the main application of the Body Gestures controlling Drone. All the codes related to this project is available on GitHub, you can access it on the request and the link is below in the annexure.

CONCLUSIONS

The tests related to this project have been performed in an open environment and a few are in a closed controlled environment, at different locations at the university campus and Elarco Design laboratory. The machine/laptop/ Notebook is used for this test is ASUS ROG STRIX, which equipped with a Ryzen processor (Ryzen 7 4800H, 8 core) and 16GB RAM, no GPU is used for the computing process, which makes it more versatile and adaptable. Because a lot of the pose recognition frameworks which are available in the market are mostly required a powerful computer with GPU, but this framework can be used in low-end devices without GPU power.

First, an investigation was carried out to view what were the other possible drones available in the market which offers the same functionality as Tello and Tello EDU. And, by doing that investigation it observed that there were a lot of other drones present in the market. But Tello played a noticeable role in the field of education, which is why it was decided to use that in this project along with that it also provides some base for future developers who wanted to start programming with the drone for fun and other applications.

Second, another research was carried out regarding the pose estimation, as we already discussed in our Pose Detection chapter, where I mentioned the different types of pose recognition models and ML frameworks available and can be used to create a project, but I choose the one which is more versatility and required only CPU.

In addition, I go through many content and paperwork which consists of controlling a drone through body movements or gestures or pose. During the research, I found a lot of scripts that can also control a drone through body movements, but these scripts were more complicated and required a lot of processing power for both CPU & GPU. Although, these scripts were provided me with the basic knowledge for programming this project.

Third, my objective of this project is to make the script more versatile, easy and adaptable, so that it can be used on any platform which is capable to run the python script. In my project, I used Windows 11 OS along with PyCharm as a Python IDE. The purpose of using PyCharm because it provides smart code completion, code inspections, on-the-fly error highlighting and quick-fixes, along with automated code refactoring and rich navigation capabilities and its good for beginners using Windows OS instead of Linux OS or Mac OS as people are more familiar with is OS which also motivates new coders to learn more. However, users can use any other Python IDE and OS according to their convenience.

In the beginning, this project seems to be so simple and easy but as I make progress and start working on the project to achieve my main application, I faced a lot of errors and failures while testing the drone flight and the code. However, from these mistakes and problems, I learned a lot of things and keep me motivated to pursue further in this project.

In this project, I have also created a few test programs to test the functionality of every function before applying them to the main application. These test codes can help others to understand the programming topology and its works. The testing codes can be used as building blocks for further developments in the application. You can easily access these testing codes and test them. These codes contain some basic manoeuvres of the Drone and the testing of Pose class along with another miscellaneous test like camera working or not, test flight take-off and landing, and testing other functions of the class.

Finally, this document can provide all the basic and advanced knowledge which allow for future developers to develop more complicated applications without any hustle and also save the time to do extensive research on the internet, since this Pose class is new in the open-source world, so there are only a few documentations present in this field as this Open Pose class still in the development phase and people are contributing more and more, and anxious to learn more in the same field.

ACRONYMS

GHUM / GHUML	Generative 3D Human Shape and Articulated Pose Models
API	Application Programming Interface
SDK	Software Development Kit
PCB	Printed Circuit Board
LED	Light Emitting Diode
EIRP	Effective Isotropic Radiated Power
mph/MPH	Miles Per Hour
kph/KPH	Kilometre Per Hour
mAh	Milliamp Hours
LiPo	Lithium-Ion Polymer Battery
Wh	Watt-hour
W	Watt
HD	High Definition
MP	Mega Pixels
IR	Infrared
ML	Machine Learning
ROI	Region of Interest
PCK	Percent of Correct Keypoints
FPS	Frame Per Second
GPU	Graphics Processing Unit
IDE	Integrated Development Environment
OS	Operating Software
GB	Gigabyte
RAM	Random-access memory

REFERENCES

[1] (2021) Tello-Python GitHub. [online] Available: https://github.com/Tushki-007/tello_sdk.git

[2] DJITelloPy: DJI Tello drone python interface using the official Tello SDK. Feel free to contribute! (github.com)

[3] (2018) MediaPipe GitHub. [online] Available: Pose - MediaPipe (google.github.io)

[4] (2021) OpenCV website. [online] Available: https://opencv.org/

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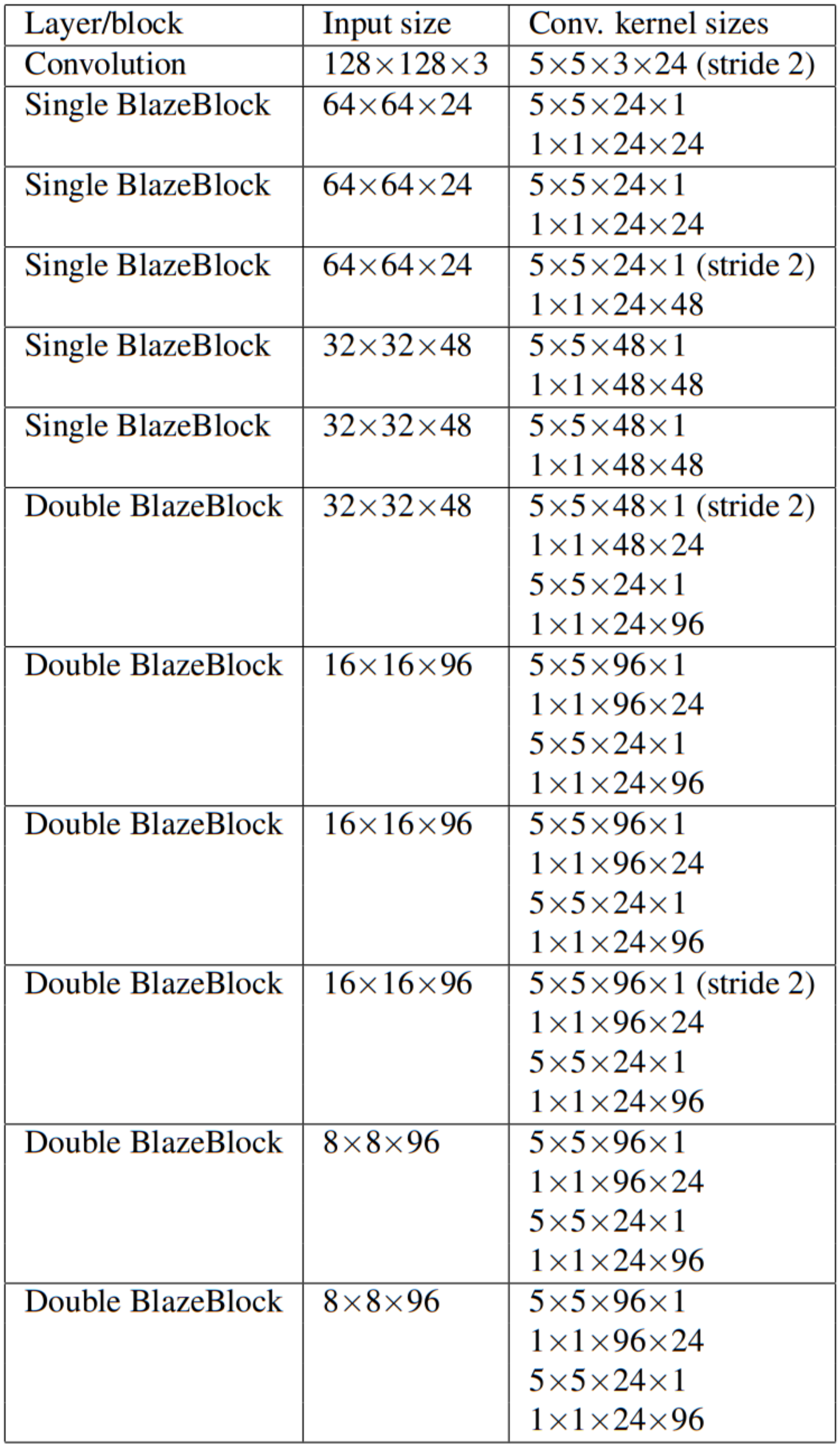
Annexe A: Feature extraction network architecture



Layer/block	Input size	Conv. kernel sizes
Convolution	128×128×3	5×5×3×24 (stride 2)
Single BlazeBlock	64×64×24	5×5×24×1 1×1×24×24
Single BlazeBlock	64×64×24	5×5×24×1 1×1×24×24
Single BlazeBlock	64×64×24	5×5×24×1 (stride 2) 1×1×24×48
Single BlazeBlock	32×32×48	5×5×48×1 1×1×48×48
Single BlazeBlock	32×32×48	5×5×48×1 1×1×48×48
Double BlazeBlock	32×32×48	5×5×48×1 (stride 2) 1×1×48×24 5×5×24×1 1×1×24×96
Double BlazeBlock	16×16×96	5×5×96×1 1×1×96×24 5×5×24×1 1×1×24×96
Double BlazeBlock	16×16×96	5×5×96×1 1×1×96×24 5×5×24×1 1×1×24×96
Double BlazeBlock	16×16×96	5×5×96×1 (stride 2) 1×1×96×24 5×5×24×1 1×1×24×96
Double BlazeBlock	8×8×96	5×5×96×1 1×1×96×24 5×5×24×1 1×1×24×96
Double BlazeBlock	8×8×96	5×5×96×1 1×1×96×24 5×5×24×1 1×1×24×96

Annexe B: GitHub References

https://github.com/geaxgx/tello-openpose

https://github.com/hanyazou/TelloPy

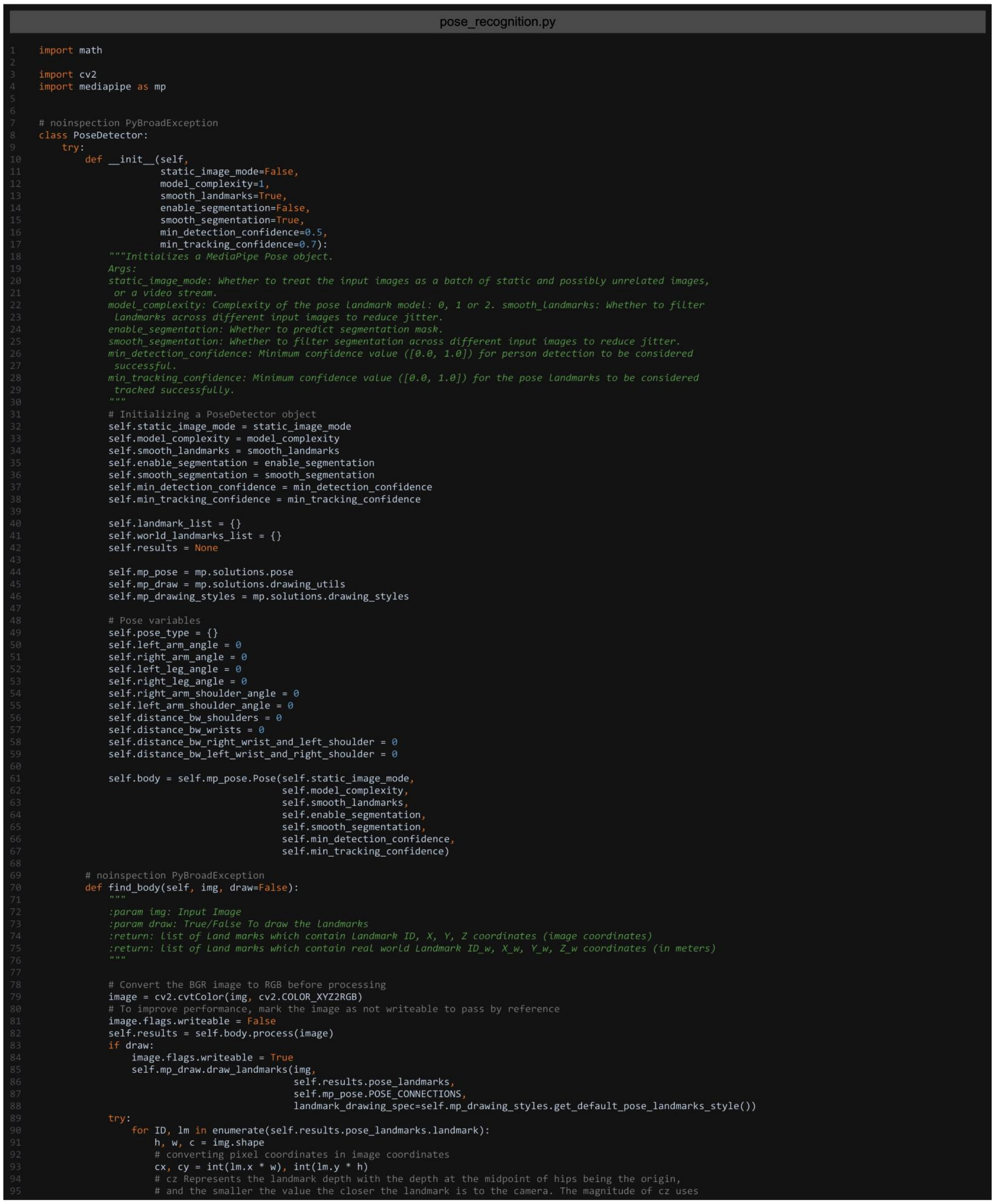
https://github.com/CMU-Perceptual-Computing-Lab/openpose

https://github.com/Ubotica/telloCV/

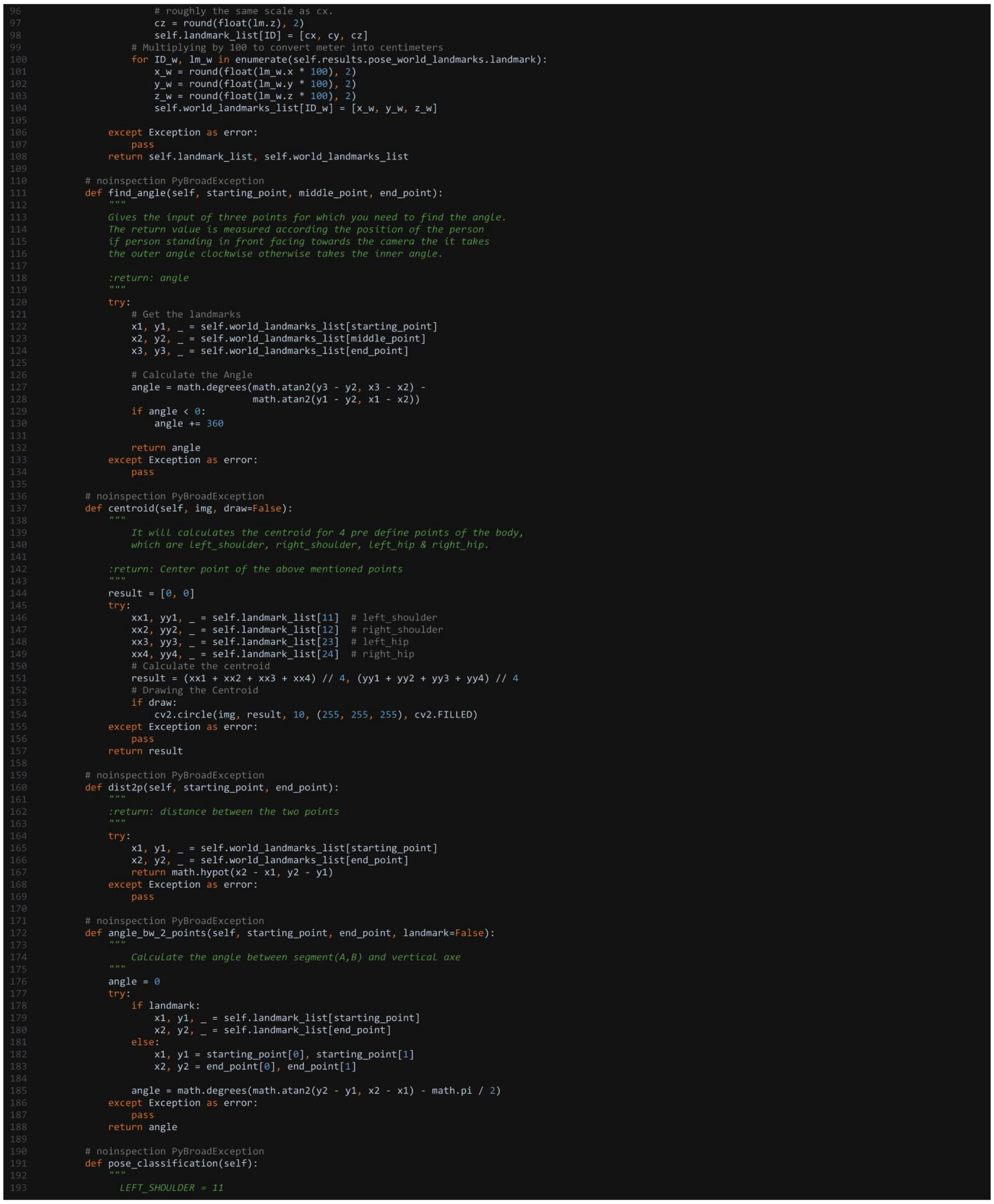
https://github.com/cvzone/cvzone

https://github.com/murtazahassan/Tello-Object-Tracking

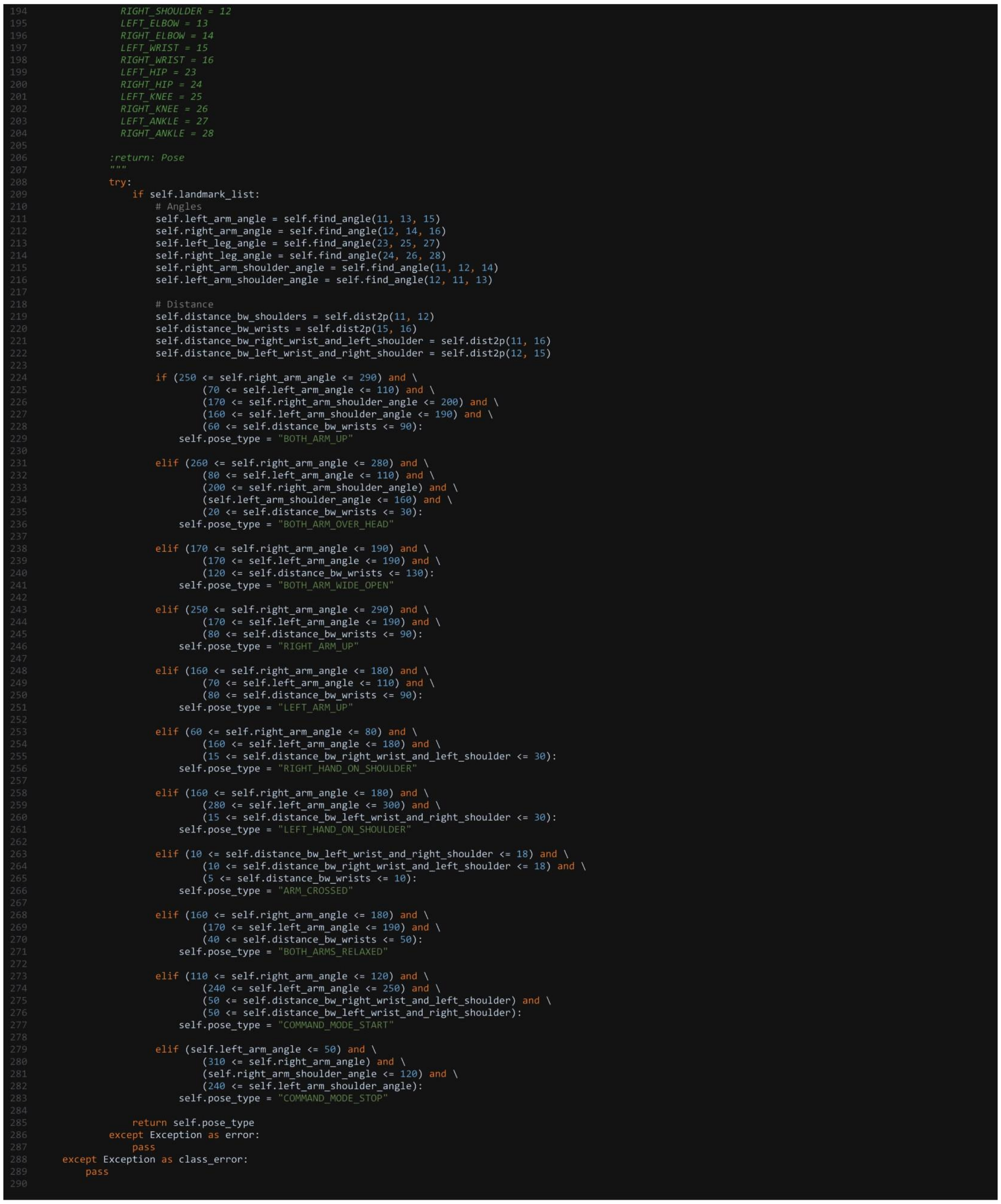
Annexe C: Pose Class and its functions


pose_recognition.py

```python
import math

import cv2
import mediapipe as mp


# noinspection PyBroadException
class PoseDetector:
    try:
        def __init__(self,
                     static_image_mode=False,
                     model_complexity=1,
                     smooth_landmarks=True,
                     enable_segmentation=False,
                     smooth_segmentation=True,
                     min_detection_confidence=0.5,
                     min_tracking_confidence=0.7):
            """Initializes a MediaPipe Pose object.
            Args:
            static_image_mode: Whether to treat the input images as a batch of static and possibly unrelated images,
             or a video stream.
            model_complexity: Complexity of the pose landmark model: 0, 1 or 2. smooth_landmarks: Whether to filter
             landmarks across different input images to reduce jitter.
            enable_segmentation: Whether to predict segmentation mask.
            smooth_segmentation: Whether to filter segmentation across different input images to reduce jitter.
            min_detection_confidence: Minimum confidence value ([0.0, 1.0]) for person detection to be considered
             successful.
            min_tracking_confidence: Minimum confidence value ([0.0, 1.0]) for the pose landmarks to be considered
             tracked successfully.
            """
            # Initializing a PoseDetector object
            self.static_image_mode = static_image_mode
            self.model_complexity = model_complexity
            self.smooth_landmarks = smooth_landmarks
            self.enable_segmentation = enable_segmentation
            self.smooth_segmentation = smooth_segmentation
            self.min_detection_confidence = min_detection_confidence
            self.min_tracking_confidence = min_tracking_confidence

            self.landmark_list = {}
            self.world_landmarks_list = {}
            self.results = None

            self.mp_pose = mp.solutions.pose
            self.mp_draw = mp.solutions.drawing_utils
            self.mp_drawing_styles = mp.solutions.drawing_styles

            # Pose variables
            self.pose_type = {}
            self.left_arm_angle = 0
            self.right_arm_angle = 0
            self.left_leg_angle = 0
            self.right_leg_angle = 0
            self.right_arm_shoulder_angle = 0
            self.left_arm_shoulder_angle = 0
            self.distance_bw_shoulders = 0
            self.distance_bw_wrists = 0
            self.distance_bw_right_wrist_and_left_shoulder = 0
            self.distance_bw_left_wrist_and_right_shoulder = 0

            self.body = self.mp_pose.Pose(self.static_image_mode,
                                          self.model_complexity,
                                          self.smooth_landmarks,
                                          self.enable_segmentation,
                                          self.smooth_segmentation,
                                          self.min_detection_confidence,
                                          self.min_tracking_confidence)

        # noinspection PyBroadException
        def find_body(self, img, draw=False):
            """
            :param img: Input Image
            :param draw: True/False To draw the landmarks
            :return: list of Land marks which contain landmark ID, X, Y, Z coordinates (image coordinates)
            :return: list of Land marks which contain real world landmark ID_w, X_w, Y_w, Z_w coordinates (in meters)
            """

            # Convert the BGR image to RGB before processing
            image = cv2.cvtColor(img, cv2.COLOR_XYZ2RGB)
            # To improve performance, mark the image as not writeable to pass by reference
            image.flags.writeable = False
            self.results = self.body.process(image)
            if draw:
                image.flags.writeable = True
                self.mp_draw.draw_landmarks(img,
                                            self.results.pose_landmarks,
                                            self.mp_pose.POSE_CONNECTIONS,
                                            landmark_drawing_spec=self.mp_drawing_styles.get_default_pose_landmarks_style())
            try:
                for ID, lm in enumerate(self.results.pose_landmarks.landmark):
                    h, w, c = img.shape
                    # converting pixel coordinates in image coordinates
                    cx, cy = int(lm.x * w), int(lm.y * h)
                    # cz Represents the landmark depth with the depth at the midpoint of hips being the origin,
                    # and the smaller the value the closer the landmark is to the camera. The magnitude of cz uses
```



```python
                    # roughly the same scale as cx.
                    cz = round(float(lm.z), 2)
                    self.landmark_list[ID] = [cx, cy, cz]
                # Multiplying by 100 to convert meter into centimeters
                for ID_w, lm_w in enumerate(self.results.pose_world_landmarks.landmark):
                    x_w = round(float(lm_w.x * 100), 2)
                    y_w = round(float(lm_w.y * 100), 2)
                    z_w = round(float(lm_w.z * 100), 2)
                    self.world_landmarks_list[ID_w] = [x_w, y_w, z_w]

            except Exception as error:
                pass
            return self.landmark_list, self.world_landmarks_list

        # noinspection PyBroadException
        def find_angle(self, starting_point, middle_point, end_point):
            """
            Gives the input of three points for which you need to find the angle.
            The return value is measured according the position of the person
            if person standing in front facing towards the camera the it takes
            the outer angle clockwise otherwise takes the inner angle.

            :return: angle
            """
            try:
                # Get the landmarks
                x1, y1, _ = self.world_landmarks_list[starting_point]
                x2, y2, _ = self.world_landmarks_list[middle_point]
                x3, y3, _ = self.world_landmarks_list[end_point]

                # Calculate the Angle
                angle = math.degrees(math.atan2(y3 - y2, x3 - x2) -
                                     math.atan2(y1 - y2, x1 - x2))
                if angle < 0:
                    angle += 360

                return angle
            except Exception as error:
                pass

        # noinspection PyBroadException
        def centroid(self, img, draw=False):
            """
                It will calculates the centroid for 4 pre define points of the body,
                which are left_shoulder, right_shoulder, left_hip & right_hip.

            :return: Center point of the above mentioned points
            """
            result = [0, 0]
            try:
                xx1, yy1, _ = self.landmark_list[11]  # left_shoulder
                xx2, yy2, _ = self.landmark_list[12]  # right_shoulder
                xx3, yy3, _ = self.landmark_list[23]  # left_hip
                xx4, yy4, _ = self.landmark_list[24]  # right_hip
                # Calculate the centroid
                result = (xx1 + xx2 + xx3 + xx4) // 4, (yy1 + yy2 + yy3 + yy4) // 4
                # Drawing the Centroid
                if draw:
                    cv2.circle(img, result, 10, (255, 255, 255), cv2.FILLED)
            except Exception as error:
                pass
            return result

        # noinspection PyBroadException
        def dist2p(self, starting_point, end_point):
            """
            :return: distance between the two points
            """
            try:
                x1, y1, _ = self.world_landmarks_list[starting_point]
                x2, y2, _ = self.world_landmarks_list[end_point]
                return math.hypot(x2 - x1, y2 - y1)
            except Exception as error:
                pass

        # noinspection PyBroadException
        def angle_bw_2_points(self, starting_point, end_point, landmark=False):
            """
                Calculate the angle between segment(A,B) and vertical axe
            """
            angle = 0
            try:
                if landmark:
                    x1, y1, _ = self.landmark_list[starting_point]
                    x2, y2, _ = self.landmark_list[end_point]
                else:
                    x1, y1 = starting_point[0], starting_point[1]
                    x2, y2 = end_point[0], end_point[1]

                angle = math.degrees(math.atan2(y2 - y1, x2 - x1) - math.pi / 2)
            except Exception as error:
                pass
            return angle

        # noinspection PyBroadException
        def pose_classification(self):
            """
              LEFT_SHOULDER = 11
```

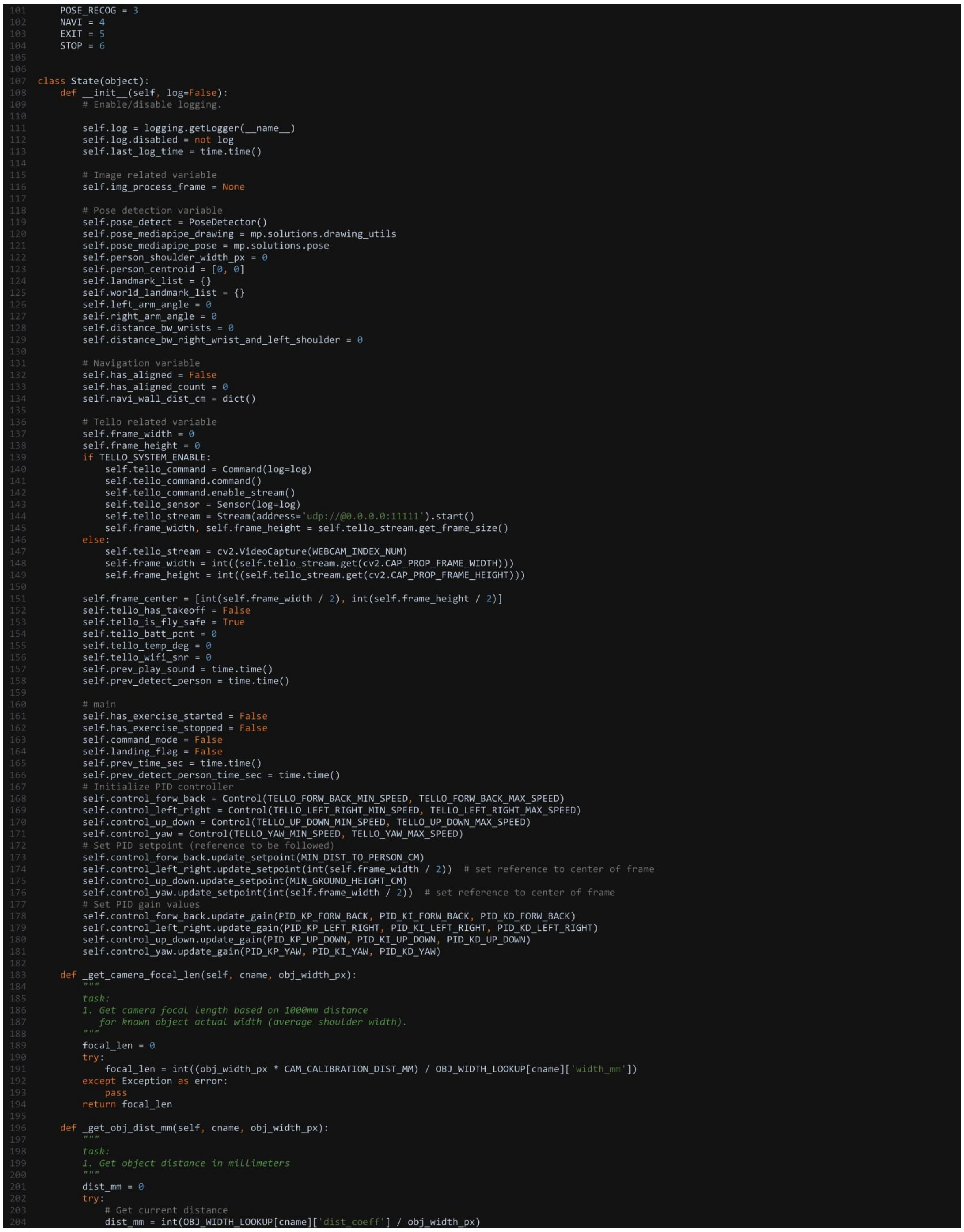


```
              RIGHT_SHOULDER = 12
              LEFT_ELBOW = 13
              RIGHT_ELBOW = 14
              LEFT_WRIST = 15
              RIGHT_WRIST = 16
              LEFT_HIP = 23
              RIGHT_HIP = 24
              LEFT_KNEE = 25
              RIGHT_KNEE = 26
              LEFT_ANKLE = 27
              RIGHT_ANKLE = 28

            :return: Pose
            """
            try:
                if self.landmark_list:
                    # Angles
                    self.left_arm_angle = self.find_angle(11, 13, 15)
                    self.right_arm_angle = self.find_angle(12, 14, 16)
                    self.left_leg_angle = self.find_angle(23, 25, 27)
                    self.right_leg_angle = self.find_angle(24, 26, 28)
                    self.right_arm_shoulder_angle = self.find_angle(11, 12, 14)
                    self.left_arm_shoulder_angle = self.find_angle(12, 11, 13)

                    # Distance
                    self.distance_bw_shoulders = self.dist2p(11, 12)
                    self.distance_bw_wrists = self.dist2p(15, 16)
                    self.distance_bw_right_wrist_and_left_shoulder = self.dist2p(11, 16)
                    self.distance_bw_left_wrist_and_right_shoulder = self.dist2p(12, 15)

                    if (250 <= self.right_arm_angle <= 290) and \
                            (70 <= self.left_arm_angle <= 110) and \
                            (170 <= self.right_arm_shoulder_angle <= 200) and \
                            (160 <= self.left_arm_shoulder_angle <= 190) and \
                            (60 <= self.distance_bw_wrists <= 90):
                        self.pose_type = "BOTH_ARM_UP"

                    elif (260 <= self.right_arm_angle <= 280) and \
                            (80 <= self.left_arm_angle <= 110) and \
                            (200 <= self.right_arm_shoulder_angle) and \
                            (self.left_arm_shoulder_angle <= 160) and \
                            (20 <= self.distance_bw_wrists <= 30):
                        self.pose_type = "BOTH_ARM_OVER_HEAD"

                    elif (170 <= self.right_arm_angle <= 190) and \
                            (170 <= self.left_arm_angle <= 190) and \
                            (120 <= self.distance_bw_wrists <= 130):
                        self.pose_type = "BOTH_ARM_WIDE_OPEN"

                    elif (250 <= self.right_arm_angle <= 290) and \
                            (170 <= self.left_arm_angle <= 190) and \
                            (80 <= self.distance_bw_wrists <= 90):
                        self.pose_type = "RIGHT_ARM_UP"

                    elif (160 <= self.right_arm_angle <= 180) and \
                            (70 <= self.left_arm_angle <= 110) and \
                            (80 <= self.distance_bw_wrists <= 90):
                        self.pose_type = "LEFT_ARM_UP"

                    elif (60 <= self.right_arm_angle <= 80) and \
                            (160 <= self.left_arm_angle <= 180) and \
                            (15 <= self.distance_bw_right_wrist_and_left_shoulder <= 30):
                        self.pose_type = "RIGHT_HAND_ON_SHOULDER"

                    elif (160 <= self.right_arm_angle <= 180) and \
                            (280 <= self.left_arm_angle <= 300) and \
                            (15 <= self.distance_bw_left_wrist_and_right_shoulder <= 30):
                        self.pose_type = "LEFT_HAND_ON_SHOULDER"

                    elif (10 <= self.distance_bw_left_wrist_and_right_shoulder <= 18) and \
                            (10 <= self.distance_bw_right_wrist_and_left_shoulder <= 18) and \
                            (5 <= self.distance_bw_wrists <= 10):
                        self.pose_type = "ARM_CROSSED"

                    elif (160 <= self.right_arm_angle <= 180) and \
                            (170 <= self.left_arm_angle <= 190) and \
                            (40 <= self.distance_bw_wrists <= 50):
                        self.pose_type = "BOTH_ARMS_RELAXED"

                    elif (110 <= self.right_arm_angle <= 120) and \
                            (240 <= self.left_arm_angle <= 250) and \
                            (50 <= self.distance_bw_right_wrist_and_left_shoulder) and \
                            (50 <= self.distance_bw_left_wrist_and_right_shoulder):
                        self.pose_type = "COMMAND_MODE_START"

                    elif (self.left_arm_angle <= 50) and \
                            (310 <= self.right_arm_angle) and \
                            (self.right_arm_shoulder_angle <= 120) and \
                            (240 <= self.left_arm_shoulder_angle):
                        self.pose_type = "COMMAND_MODE_STOP"

                return self.pose_type
            except Exception as error:
                pass
    except Exception as class_error:
        pass
```

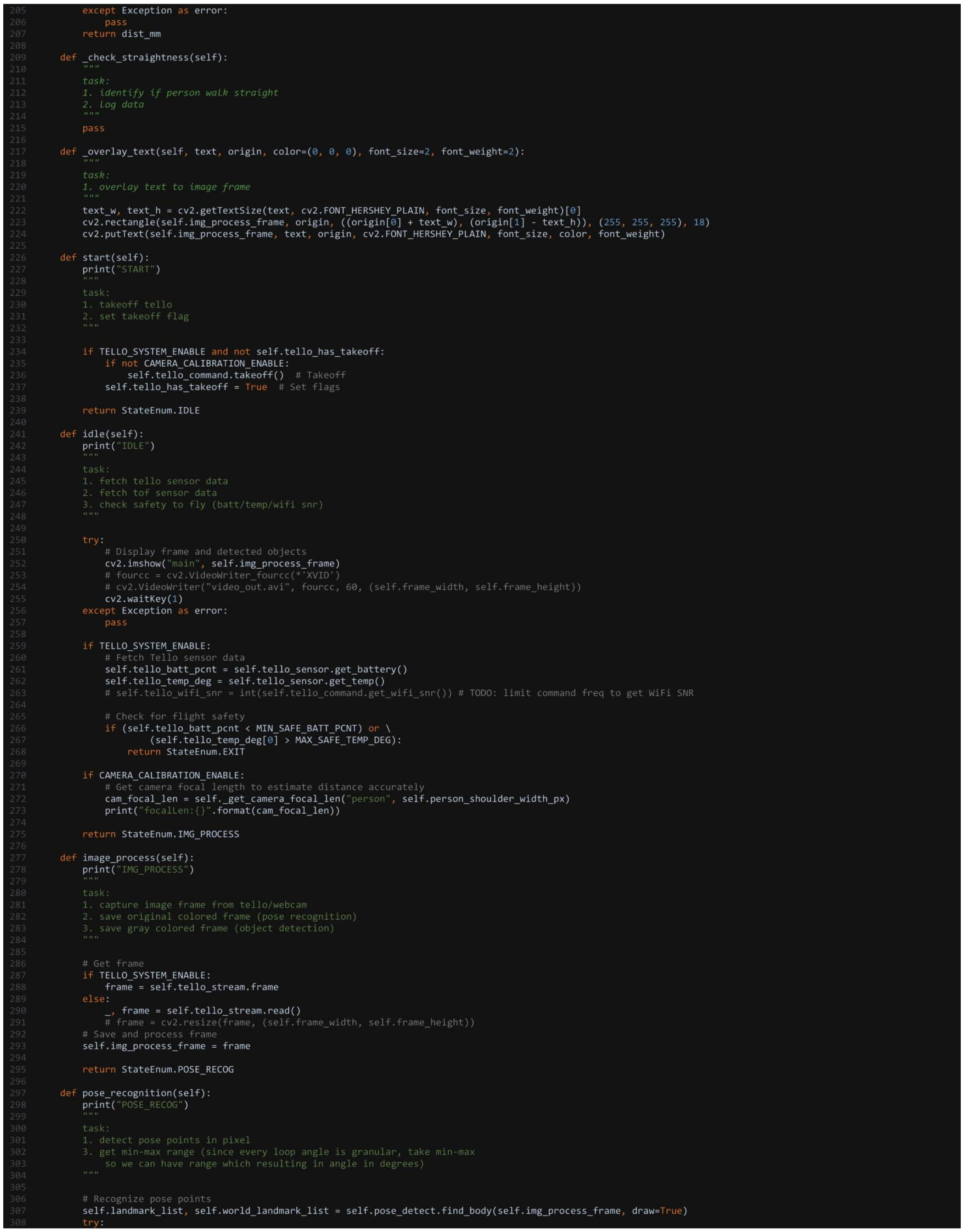
Annexe D: State Class and its functions

State.py

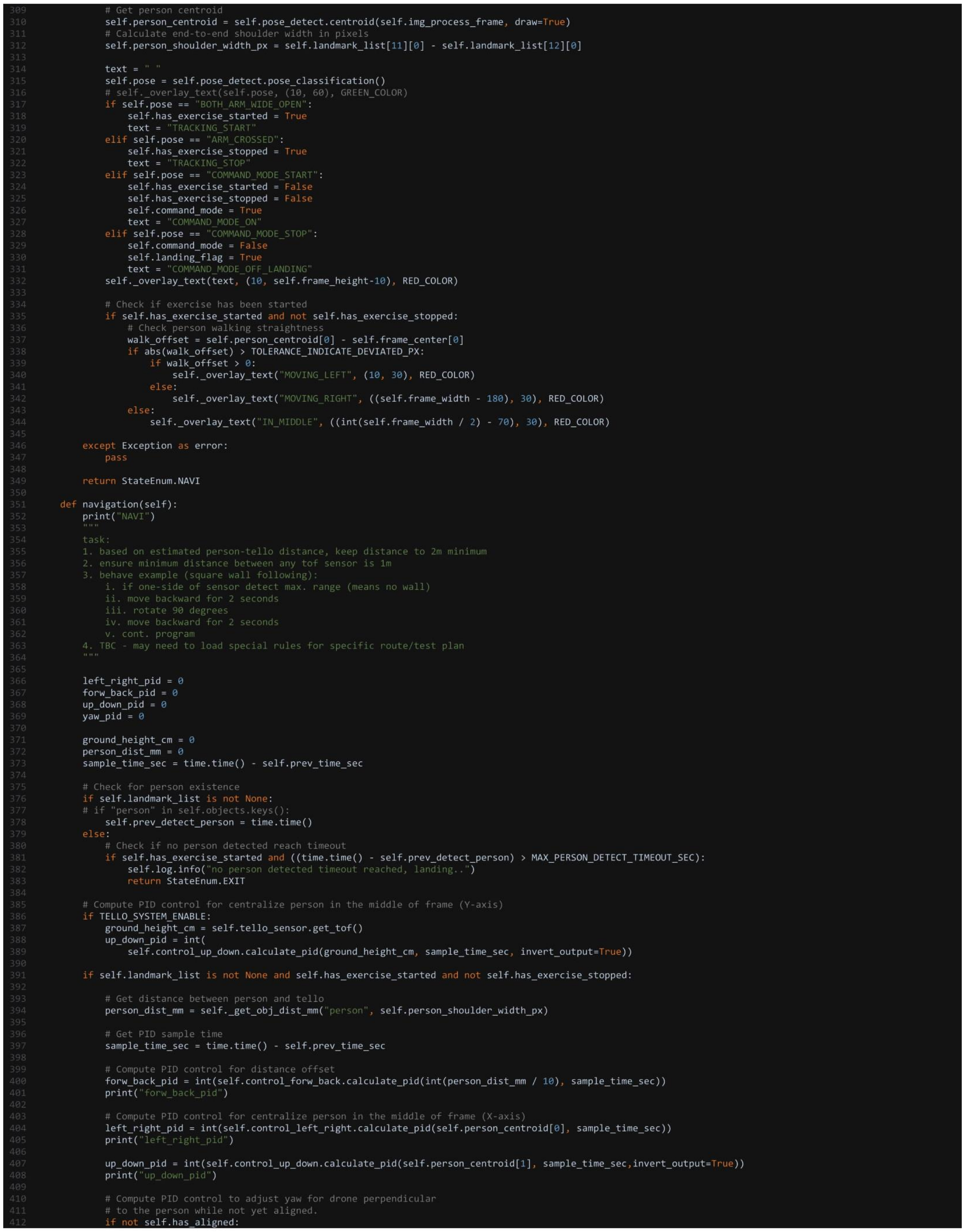
```python
"""
@brief      This is system state program
"""

import enum
import logging
import time
from datetime import datetime

import cv2
import mediapipe as mp

from Control import Control
from supports.pose_recognition.pose_recognition import PoseDetector
from supports.tello_sdk.Command import Command
from supports.tello_sdk.Sensor import Sensor
from supports.tello_sdk.Stream import Stream

# Debug/development setting
DEBUG_PRINT = False
LOCAL_SENSOR_ENABLE = False
TELLO_SYSTEM_ENABLE = False
CAMERA_CALIBRATION_ENABLE = False
WEBCAM_INDEX_NUM = "assets/test.mp4"


# Behavior parameter
MAX_ALIGNMENT_OFFSET_PX = 10
ALIGNMENT_SAMPLE_COUNT = 10

# Tello flight parameter
MIN_DIST_TO_PERSON_CM = 350
MIN_DIST_TO_WALL_CM = 100
MIN_GROUND_HEIGHT_CM = 150
TOLERANCE_INDICATE_DEVIATED_PX = 50  # this to tolerate the drone left/right motion stability

LOG_SAMPLE_TIME_SEC = 0.5

# Tello flight safety parameter
MIN_SAFE_BATT_PCNT = 25
MAX_SAFE_TEMP_DEG = 85
MIN_SAFE_WIFI_SNR = 70
MAX_PERSON_DETECT_TIMEOUT_SEC = 15

# PID gain values for control Tello maneuver
PID_KP_FORW_BACK = 0.4
PID_KI_FORW_BACK = 0.0
PID_KD_FORW_BACK = 0.0

PID_KP_LEFT_RIGHT = 0.10
PID_KI_LEFT_RIGHT = 0.0
PID_KD_LEFT_RIGHT = 0.0

PID_KP_UP_DOWN = 0.8
PID_KI_UP_DOWN = 0.0
PID_KD_UP_DOWN = 0.0

PID_KP_YAW = 0.10
PID_KI_YAW = 0.0
PID_KD_YAW = 0.0

# Tello RC speed limiter
TELLO_FORW_BACK_MIN_SPEED = -30
TELLO_FORW_BACK_MAX_SPEED = 30
TELLO_LEFT_RIGHT_MIN_SPEED = -30
TELLO_LEFT_RIGHT_MAX_SPEED = 30
TELLO_UP_DOWN_MIN_SPEED = -30
TELLO_UP_DOWN_MAX_SPEED = 30
TELLO_YAW_MIN_SPEED = -10
TELLO_YAW_MAX_SPEED = 10

# Focal length:
# >> Tello camera = 670
# >> Logitech C270 = 480
CAM_FOCAL_LENGTH = 670
CAM_CALIBRATION_DIST_MM = 1000
AVG_MALE_SHOULDER_WIDTH_MM = 411

# Object width table used to lookup/compute known length as reference
OBJ_WIDTH_LOOKUP = {
    "person": {
        "width_mm": AVG_MALE_SHOULDER_WIDTH_MM,
        "dist_coeff": (CAM_FOCAL_LENGTH * AVG_MALE_SHOULDER_WIDTH_MM)
    }
}

BLACK_COLOR = (0, 0, 0)
RED_COLOR = (95, 95, 255)
GREEN_COLOR = (97, 233, 128)
YELLOW_COLOR = (0, 255, 255)
WHITE_COLOR = (255, 255, 255)
BLUE_COLOR = (255, 233, 66)
FONT = cv2.FONT_HERSHEY_SIMPLEX


# System state enum
class StateEnum(enum.Enum):
    START = 0
    IDLE = 1
    IMG_PROCESS = 2
```



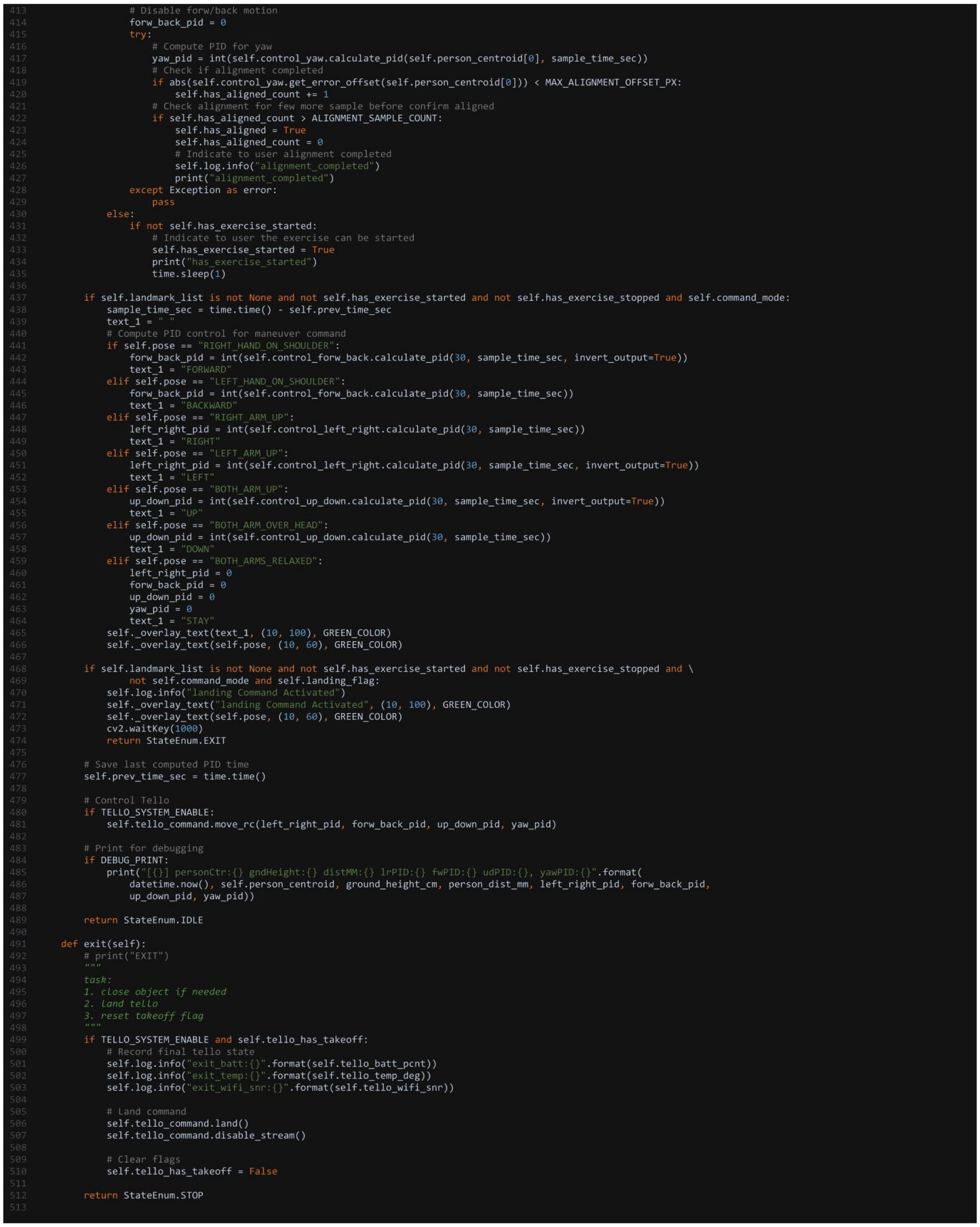
```python
    POSE_RECOG = 3
    NAVI = 4
    EXIT = 5
    STOP = 6


class State(object):
    def __init__(self, log=False):
        # Enable/disable logging.

        self.log = logging.getLogger(__name__)
        self.log.disabled = not log
        self.last_log_time = time.time()

        # Image related variable
        self.img_process_frame = None

        # Pose detection variable
        self.pose_detect = PoseDetector()
        self.pose_mediapipe_drawing = mp.solutions.drawing_utils
        self.pose_mediapipe_pose = mp.solutions.pose
        self.person_shoulder_width_px = 0
        self.person_centroid = [0, 0]
        self.landmark_list = {}
        self.world_landmark_list = {}
        self.left_arm_angle = 0
        self.right_arm_angle = 0
        self.distance_bw_wrists = 0
        self.distance_bw_right_wrist_and_left_shoulder = 0

        # Navigation variable
        self.has_aligned = False
        self.has_aligned_count = 0
        self.navi_wall_dist_cm = dict()

        # Tello related variable
        self.frame_width = 0
        self.frame_height = 0
        if TELLO_SYSTEM_ENABLE:
            self.tello_command = Command(log=log)
            self.tello_command.command()
            self.tello_command.enable_stream()
            self.tello_sensor = Sensor(log=log)
            self.tello_stream = Stream(address='udp://@0.0.0.0:11111').start()
            self.frame_width, self.frame_height = self.tello_stream.get_frame_size()
        else:
            self.tello_stream = cv2.VideoCapture(WEBCAM_INDEX_NUM)
            self.frame_width = int((self.tello_stream.get(cv2.CAP_PROP_FRAME_WIDTH)))
            self.frame_height = int((self.tello_stream.get(cv2.CAP_PROP_FRAME_HEIGHT)))

        self.frame_center = [int(self.frame_width / 2), int(self.frame_height / 2)]
        self.tello_has_takeoff = False
        self.tello_is_fly_safe = True
        self.tello_batt_pcnt = 0
        self.tello_temp_deg = 0
        self.tello_wifi_snr = 0
        self.prev_play_sound = time.time()
        self.prev_detect_person = time.time()

        # main
        self.has_exercise_started = False
        self.has_exercise_stopped = False
        self.command_mode = False
        self.landing_flag = False
        self.prev_time_sec = time.time()
        self.prev_detect_person_time_sec = time.time()
        # Initialize PID controller
        self.control_forw_back = Control(TELLO_FORW_BACK_MIN_SPEED, TELLO_FORW_BACK_MAX_SPEED)
        self.control_left_right = Control(TELLO_LEFT_RIGHT_MIN_SPEED, TELLO_LEFT_RIGHT_MAX_SPEED)
        self.control_up_down = Control(TELLO_UP_DOWN_MIN_SPEED, TELLO_UP_DOWN_MAX_SPEED)
        self.control_yaw = Control(TELLO_YAW_MIN_SPEED, TELLO_YAW_MAX_SPEED)
        # Set PID setpoint (reference to be followed)
        self.control_forw_back.update_setpoint(MIN_DIST_TO_PERSON_CM)
        self.control_left_right.update_setpoint(int(self.frame_width / 2))  # set reference to center of frame
        self.control_up_down.update_setpoint(MIN_GROUND_HEIGHT_CM)
        self.control_yaw.update_setpoint(int(self.frame_width / 2))  # set reference to center of frame
        # Set PID gain values
        self.control_forw_back.update_gain(PID_KP_FORW_BACK, PID_KI_FORW_BACK, PID_KD_FORW_BACK)
        self.control_left_right.update_gain(PID_KP_LEFT_RIGHT, PID_KI_LEFT_RIGHT, PID_KD_LEFT_RIGHT)
        self.control_up_down.update_gain(PID_KP_UP_DOWN, PID_KI_UP_DOWN, PID_KD_UP_DOWN)
        self.control_yaw.update_gain(PID_KP_YAW, PID_KI_YAW, PID_KD_YAW)

    def _get_camera_focal_len(self, cname, obj_width_px):
        """
        task:
        1. Get camera focal length based on 1000mm distance
           for known object actual width (average shoulder width).
        """
        focal_len = 0
        try:
            focal_len = int((obj_width_px * CAM_CALIBRATION_DIST_MM) / OBJ_WIDTH_LOOKUP[cname]['width_mm'])
        except Exception as error:
            pass
        return focal_len

    def _get_obj_dist_mm(self, cname, obj_width_px):
        """
        task:
        1. Get object distance in millimeters
        """
        dist_mm = 0
        try:
            # Get current distance
            dist_mm = int(OBJ_WIDTH_LOOKUP[cname]['dist_coeff'] / obj_width_px)
```



```python
        except Exception as error:
            pass
        return dist_mm

    def _check_straightness(self):
        """
        task:
        1. identify if person walk straight
        2. log data
        """
        pass

    def _overlay_text(self, text, origin, color=(0, 0, 0), font_size=2, font_weight=2):
        """
        task:
        1. overlay text to image frame
        """
        text_w, text_h = cv2.getTextSize(text, cv2.FONT_HERSHEY_PLAIN, font_size, font_weight)[0]
        cv2.rectangle(self.img_process_frame, origin, ((origin[0] + text_w), (origin[1] - text_h)), (255, 255, 255), 18)
        cv2.putText(self.img_process_frame, text, origin, cv2.FONT_HERSHEY_PLAIN, font_size, color, font_weight)

    def start(self):
        print("START")
        """
        task:
        1. takeoff tello
        2. set takeoff flag
        """

        if TELLO_SYSTEM_ENABLE and not self.tello_has_takeoff:
            if not CAMERA_CALIBRATION_ENABLE:
                self.tello_command.takeoff()  # Takeoff
            self.tello_has_takeoff = True  # Set flags

        return StateEnum.IDLE

    def idle(self):
        print("IDLE")
        """
        task:
        1. fetch tello sensor data
        2. fetch tof sensor data
        3. check safety to fly (batt/temp/wifi snr)
        """

        try:
            # Display frame and detected objects
            cv2.imshow("main", self.img_process_frame)
            # fourcc = cv2.VideoWriter_fourcc(*'XVID')
            # cv2.VideoWriter("video_out.avi", fourcc, 60, (self.frame_width, self.frame_height))
            cv2.waitKey(1)
        except Exception as error:
            pass

        if TELLO_SYSTEM_ENABLE:
            # Fetch Tello sensor data
            self.tello_batt_pcnt = self.tello_sensor.get_battery()
            self.tello_temp_deg = self.tello_sensor.get_temp()
            # self.tello_wifi_snr = int(self.tello_command.get_wifi_snr()) # TODO: limit command freq to get WiFi SNR

            # Check for flight safety
            if (self.tello_batt_pcnt < MIN_SAFE_BATT_PCNT) or \
                    (self.tello_temp_deg[0] > MAX_SAFE_TEMP_DEG):
                return StateEnum.EXIT

        if CAMERA_CALIBRATION_ENABLE:
            # Get camera focal length to estimate distance accurately
            cam_focal_len = self._get_camera_focal_len("person", self.person_shoulder_width_px)
            print("focalLen:{}".format(cam_focal_len))

        return StateEnum.IMG_PROCESS

    def image_process(self):
        print("IMG_PROCESS")
        """
        task:
        1. capture image frame from tello/webcam
        2. save original colored frame (pose recognition)
        3. save gray colored frame (object detection)
        """

        # Get frame
        if TELLO_SYSTEM_ENABLE:
            frame = self.tello_stream.frame
        else:
            _, frame = self.tello_stream.read()
            # frame = cv2.resize(frame, (self.frame_width, self.frame_height))
        # Save and process frame
        self.img_process_frame = frame

        return StateEnum.POSE_RECOG

    def pose_recognition(self):
        print("POSE_RECOG")
        """
        task:
        1. detect pose points in pixel
        3. get min-max range (since every loop angle is granular, take min-max
           so we can have range which resulting in angle in degrees)
        """

        # Recognize pose points
        self.landmark_list, self.world_landmark_list = self.pose_detect.find_body(self.img_process_frame, draw=True)
        try:
```

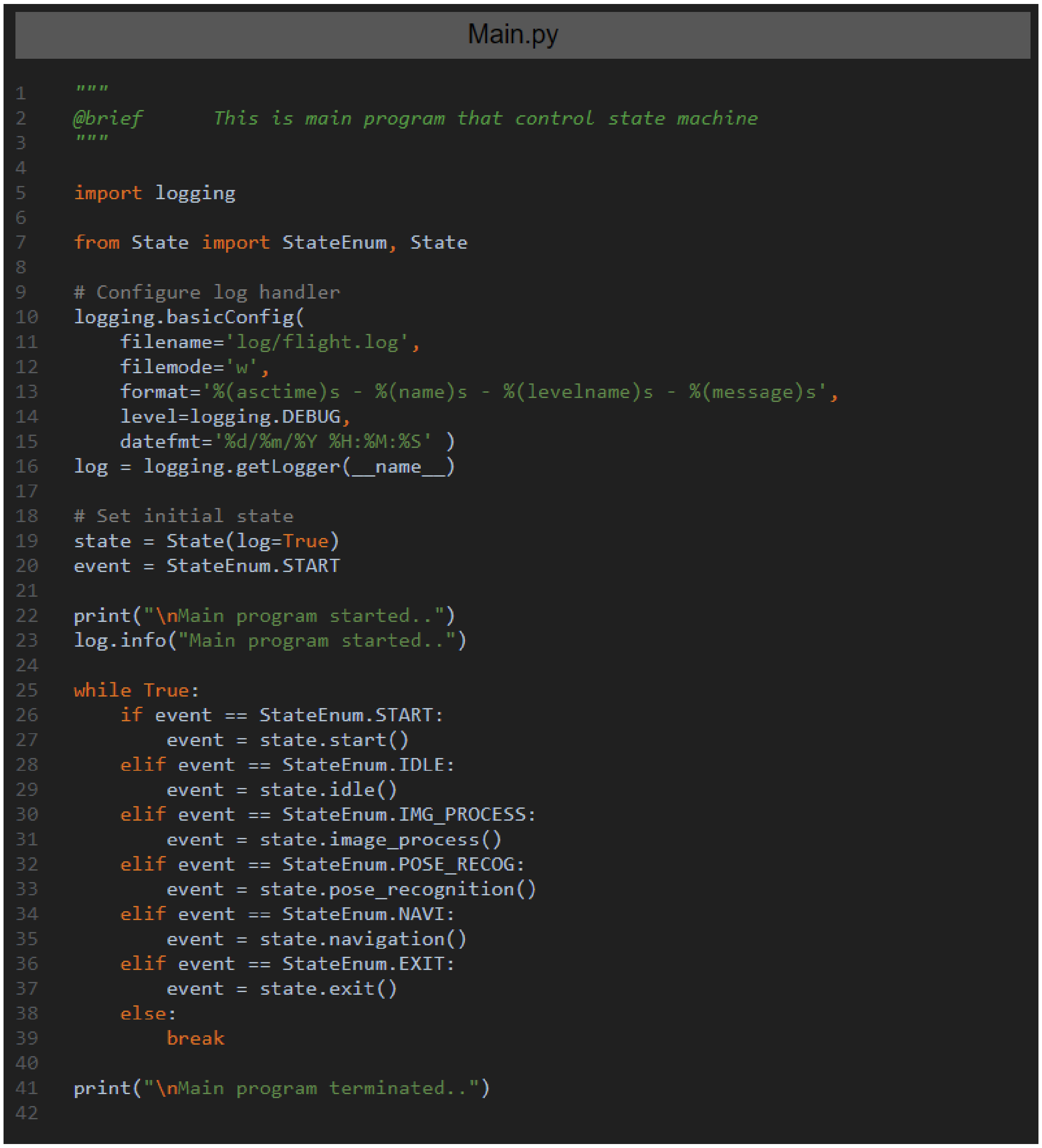


```python
            # Get person centroid
            self.person_centroid = self.pose_detect.centroid(self.img_process_frame, draw=True)
            # Calculate end-to-end shoulder width in pixels
            self.person_shoulder_width_px = self.landmark_list[11][0] - self.landmark_list[12][0]

            text = " "
            self.pose = self.pose_detect.pose_classification()
            # self._overlay_text(self.pose, (10, 60), GREEN_COLOR)
            if self.pose == "BOTH_ARM_WIDE_OPEN":
                self.has_exercise_started = True
                text = "TRACKING_START"
            elif self.pose == "ARM_CROSSED":
                self.has_exercise_stopped = True
                text = "TRACKING_STOP"
            elif self.pose == "COMMAND_MODE_START":
                self.has_exercise_started = False
                self.has_exercise_stopped = False
                self.command_mode = True
                text = "COMMAND_MODE_ON"
            elif self.pose == "COMMAND_MODE_STOP":
                self.command_mode = False
                self.landing_flag = True
                text = "COMMAND_MODE_OFF_LANDING"
            self._overlay_text(text, (10, self.frame_height-10), RED_COLOR)

            # Check if exercise has been started
            if self.has_exercise_started and not self.has_exercise_stopped:
                # Check person walking straightness
                walk_offset = self.person_centroid[0] - self.frame_center[0]
                if abs(walk_offset) > TOLERANCE_INDICATE_DEVIATED_PX:
                    if walk_offset > 0:
                        self._overlay_text("MOVING_LEFT", (10, 30), RED_COLOR)
                    else:
                        self._overlay_text("MOVING_RIGHT", ((self.frame_width - 180), 30), RED_COLOR)
                else:
                    self._overlay_text("IN_MIDDLE", ((int(self.frame_width / 2) - 70), 30), RED_COLOR)

        except Exception as error:
            pass

        return StateEnum.NAVI

    def navigation(self):
        print("NAVI")
        """
        task:
        1. based on estimated person-tello distance, keep distance to 2m minimum
        2. ensure minimum distance between any tof sensor is 1m
        3. behave example (square wall following):
            i. if one-side of sensor detect max. range (means no wall)
            ii. move backward for 2 seconds
            iii. rotate 90 degrees
            iv. move backward for 2 seconds
            v. cont. program
        4. TBC - may need to load special rules for specific route/test plan
        """

        left_right_pid = 0
        forw_back_pid = 0
        up_down_pid = 0
        yaw_pid = 0

        ground_height_cm = 0
        person_dist_mm = 0
        sample_time_sec = time.time() - self.prev_time_sec

        # Check for person existence
        if self.landmark_list is not None:
        # if "person" in self.objects.keys():
            self.prev_detect_person = time.time()
        else:
            # Check if no person detected reach timeout
            if self.has_exercise_started and ((time.time() - self.prev_detect_person) > MAX_PERSON_DETECT_TIMEOUT_SEC):
                self.log.info("no person detected timeout reached, landing..")
                return StateEnum.EXIT

        # Compute PID control for centralize person in the middle of frame (Y-axis)
        if TELLO_SYSTEM_ENABLE:
            ground_height_cm = self.tello_sensor.get_tof()
            up_down_pid = int(
                self.control_up_down.calculate_pid(ground_height_cm, sample_time_sec, invert_output=True))

        if self.landmark_list is not None and self.has_exercise_started and not self.has_exercise_stopped:

            # Get distance between person and tello
            person_dist_mm = self._get_obj_dist_mm("person", self.person_shoulder_width_px)

            # Get PID sample time
            sample_time_sec = time.time() - self.prev_time_sec

            # Compute PID control for distance offset
            forw_back_pid = int(self.control_forw_back.calculate_pid(int(person_dist_mm / 10), sample_time_sec))
            print("forw_back_pid")

            # Compute PID control for centralize person in the middle of frame (X-axis)
            left_right_pid = int(self.control_left_right.calculate_pid(self.person_centroid[0], sample_time_sec))
            print("left_right_pid")

            up_down_pid = int(self.control_up_down.calculate_pid(self.person_centroid[1], sample_time_sec,invert_output=True))
            print("up_down_pid")

            # Compute PID control to adjust yaw for drone perpendicular
            # to the person while not yet aligned.
            if not self.has_aligned:
```



```python
                # Disable forw/back motion
                forw_back_pid = 0
                try:
                    # Compute PID for yaw
                    yaw_pid = int(self.control_yaw.calculate_pid(self.person_centroid[0], sample_time_sec))
                    # Check if alignment completed
                    if abs(self.control_yaw.get_error_offset(self.person_centroid[0])) < MAX_ALIGNMENT_OFFSET_PX:
                        self.has_aligned_count += 1
                    # Check alignment for few more sample before confirm aligned
                    if self.has_aligned_count > ALIGNMENT_SAMPLE_COUNT:
                        self.has_aligned = True
                        self.has_aligned_count = 0
                        # Indicate to user alignment completed
                        self.log.info("alignment_completed")
                        print("alignment_completed")
                except Exception as error:
                    pass
            else:
                if not self.has_exercise_started:
                    # Indicate to user the exercise can be started
                    self.has_exercise_started = True
                    print("has_exercise_started")
                    time.sleep(1)

        if self.landmark_list is not None and not self.has_exercise_started and not self.has_exercise_stopped and self.command_mode:
            sample_time_sec = time.time() - self.prev_time_sec
            text_1 = " "
            # Compute PID control for maneuver command
            if self.pose == "RIGHT_HAND_ON_SHOULDER":
                forw_back_pid = int(self.control_forw_back.calculate_pid(30, sample_time_sec, invert_output=True))
                text_1 = "FORWARD"
            elif self.pose == "LEFT_HAND_ON_SHOULDER":
                forw_back_pid = int(self.control_forw_back.calculate_pid(30, sample_time_sec))
                text_1 = "BACKWARD"
            elif self.pose == "RIGHT_ARM_UP":
                left_right_pid = int(self.control_left_right.calculate_pid(30, sample_time_sec))
                text_1 = "RIGHT"
            elif self.pose == "LEFT_ARM_UP":
                left_right_pid = int(self.control_left_right.calculate_pid(30, sample_time_sec, invert_output=True))
                text_1 = "LEFT"
            elif self.pose == "BOTH_ARM_UP":
                up_down_pid = int(self.control_up_down.calculate_pid(30, sample_time_sec, invert_output=True))
                text_1 = "UP"
            elif self.pose == "BOTH_ARM_OVER_HEAD":
                up_down_pid = int(self.control_up_down.calculate_pid(30, sample_time_sec))
                text_1 = "DOWN"
            elif self.pose == "BOTH_ARMS_RELAXED":
                left_right_pid = 0
                forw_back_pid = 0
                up_down_pid = 0
                yaw_pid = 0
                text_1 = "STAY"
            self._overlay_text(text_1, (10, 100), GREEN_COLOR)
            self._overlay_text(self.pose, (10, 60), GREEN_COLOR)

        if self.landmark_list is not None and not self.has_exercise_started and not self.has_exercise_stopped and \
                not self.command_mode and self.landing_flag:
            self.log.info("landing Command Activated")
            self._overlay_text("landing Command Activated", (10, 100), GREEN_COLOR)
            self._overlay_text(self.pose, (10, 60), GREEN_COLOR)
            cv2.waitKey(1000)
            return StateEnum.EXIT

        # Save last computed PID time
        self.prev_time_sec = time.time()

        # Control Tello
        if TELLO_SYSTEM_ENABLE:
            self.tello_command.move_rc(left_right_pid, forw_back_pid, up_down_pid, yaw_pid)

        # Print for debugging
        if DEBUG_PRINT:
            print("[{}] personCtr:{} gndHeight:{} distMM:{} lrPID:{} fwPID:{} udPID:{}, yawPID:{}".format(
                datetime.now(), self.person_centroid, ground_height_cm, person_dist_mm, left_right_pid, forw_back_pid,
                up_down_pid, yaw_pid))

        return StateEnum.IDLE

    def exit(self):
        # print("EXIT")
        """
        task:
        1. close object if needed
        2. land tello
        3. reset takeoff flag
        """
        if TELLO_SYSTEM_ENABLE and self.tello_has_takeoff:
            # Record final tello state
            self.log.info("exit_batt:{}".format(self.tello_batt_pcnt))
            self.log.info("exit_temp:{}".format(self.tello_temp_deg))
            self.log.info("exit_wifi_snr:{}".format(self.tello_wifi_snr))

            # Land command
            self.tello_command.land()
            self.tello_command.disable_stream()

            # Clear flags
            self.tello_has_takeoff = False

        return StateEnum.STOP
```

Annexe E: Main functions



Main.py

```python
"""
@brief      This is main program that control state machine
"""

import logging

from State import StateEnum, State

# Configure log handler
logging.basicConfig(
    filename='log/flight.log',
    filemode='w',
    format='%(asctime)s - %(name)s - %(levelname)s - %(message)s',
    level=logging.DEBUG,
    datefmt='%d/%m/%Y %H:%M:%S' )
log = logging.getLogger(__name__)

# Set initial state
state = State(log=True)
event = StateEnum.START

print("\nMain program started..")
log.info("Main program started..")

while True:
    if event == StateEnum.START:
        event = state.start()
    elif event == StateEnum.IDLE:
        event = state.idle()
    elif event == StateEnum.IMG_PROCESS:
        event = state.image_process()
    elif event == StateEnum.POSE_RECOG:
        event = state.pose_recognition()
    elif event == StateEnum.NAVI:
        event = state.navigation()
    elif event == StateEnum.EXIT:
        event = state.exit()
    else:
        break

print("\nMain program terminated..")
```