Machine Vision Involving DJI Tello Drones: Object Detection and Behavioral Response

Nicholas Nguyen, Tanvi Mistry,
Tubatsi Moloi, and Manjote Singh

Abstract – **There are numerous benefits to developing the DJI Tello Drone for our needs. By developing a superior control system, we can accomplish the unthinkable. The DJI Tello Drone can recognize odd objects and colors using machine vision thanks to the integration of Tello SDK and OpenCV[1]. This allows the drone to be able to act and react based on these factors and where they are located based on the position of the Tello Drone. Additionally, we will be using MediaPipe, a machine learning platform, to advance object tracking and recognition. MediaPipe is designed to detect Hand Key Points[4]. Our hands are intricately shaped, therefore MediaPipe must recognize all of the joints and features of our hands, including the fingertips, knuckles of each finger, and the wrist, and will distinguish between the different fingers based on these features[4]. Our system can recognize each of our five fingers, enabling it to recognize hand motions and respond in accordance with those movements. These basic drones, equipped with cameras, are capable of much more than simply flying about. They can recognize and respond to practically everything that is thrown at them. Drones can accomplish the unthinkable and will probably play a major role in the restructuring of our way of life.**

Keywords* – *Machine Vision, Object Recognition, Tello SDK, OpenCV, MediaPipe, Hand Keypoints

I. INTRODUCTION

The DJI Tello drone is a simple-to-operate, lightweight device that can fly up and down, flip eight various ways, and capture brief films. The Tello app or a Bluetooth device that is compatible with Tello may be used to operate the drone. It's remarkable that you can even operate the drone while wearing a virtual reality headset.

In addition, Tello drones are excellent teaching tools. The drone and its attachments may be practiced being programmed using Scratch. MIT created the block-based programming language known as Scratch. Its primary function is to instruct users on how to develop the core reasoning abilities necessary for coding. Users are taught how to think creatively and collaborate with others in order to achieve this.

The Tello drone, however, is not only for novice programmers. The bulk of my flights were little under 10 minutes, or around that time. The drone features a micro-USB plug, which is ideal for changing the battery while you're out and about, but the battery life is limited [9]. Replacement batteries may be purchased. The battery has to be charged for slightly over an hour. This may be ultimately due to the size of the battery as well, it is nimble and very small. A picture of the DJI Tello Drone’s battery is shown below.

DJI Tello Drone Battery

In collaboration with DJI and Intel, the DJI Drone unveiled the Tello (for the hand control system and processor, respectively). In essence, it was a scaled-down version of the Spark with more functionality than its $120 price tag might imply. A feature of all the specs of the DJI Tello Drone are shown below as reference.

DJI Tello Drone Specs Demonstration

The drone's introduction was perfectly timed for the study since it satisfied the requirements for choosing a drone for research.

The majority of the DJI Tello's 80 grams weight may be attributed to its battery. Its small size (5 x 5 x 1.3 inches) makes it easily transportable and useful for use in the field. According to others, the DJI Spark, which also has a small frame and just two colors, inspired the little drone's design. Tello's body is designed to withstand impacts as well, as it is built entirely[9].

The drone has a variety of hand modes, including two-hand speeds (Slow and Fast), automatic take-off or landing, 8D Flips, 360-degree Panoramic Shot, Bounce mode, Throw and Go, Up and Away, and the Circle which causes the drone to orbit; all of which have provided variations in the shots and clips captured in each permaculture site. A picture of someone holding the DJI Tello Drone in their hand is shown below as reference.

DJI Tello Drone Hand Comparison

Using the drone for field research presented some difficult picture stabilization challenges. The fact that there were moments when the weather turned bad, with light rain and high gusts, happened by coincidence during the site visits Tello's Electronic Image Stabilization (EIS) technology helped to resolve this issue and lessened shaking and blurring despite the absence of a mechanical gimbal, which was responsible for the camera's image stabilization on the heavy-duty drones. The team's drone operators have improved their drone handling and exceptional shot-taking abilities because of the varied, unexpected weather conditions and topography of the many places visited.

Most people immediately picture a high-tech military weapon hovering above the sky while the pilot is located in a control center hundreds of miles away when they hear the word "drone." That isn't exactly what we're discussing here. Recently, quadcopters have been referred to as remote-control aircraft with four propellers, using the same terminology.

These micro-aircraft have gotten smaller, cheaper, and easier to use as flight stability and control algorithms have become more complex. The virtual wireless controllers in the Tello app or a suitable remote controller may be used to manually operate the DJI Tello Drone[7].

Additionally, it features a few Intelligent Flight Modes that may be used to program Tello to execute maneuvers on its own. The Tello also has a flying mode that it may revert to under specific conditions [4]. The Tello uses its Vision Positioning System to autonomously stabilize itself when being flown manually. The aircraft switches automatically to Attitude mode if the Vision Positioning System is not accessible due to the circumstances.

The image stabilization was one of the difficult components of using the drone for fieldwork. It was a coincidence that there were occasions during the site visits when the weather became bad, with a light rain and high gusts [5].

Tello's Electronic Image Stabilization function helped to solve this problem and minimize shaking and blurring despite the heavy-duty drones' lack of a mechanical gimbal, which was responsible for camera image stabilization [6]. The team's drone operators have improved their control of the drone and ability to capture amazing photos due to the varied, unexpected weather conditions and topography of the many places visited.

The Tello was created for use by kids and beginning drone pilots, unlike other drones that require training. It can thanks to its visual positioning system [2].

It takes practice to maneuver the aircraft smoothly enough to get beautiful pictures and films[5]. However, you will finally arrive. A portable controller with two thumb sticks is typically used to operate drones as shown below.

II. PURPOSE AND GOAL

Our goal for this project is to research and discover possible use cases for Tello Drones that go beyond simple mobile camera work. The drones' ability to be programmed offers a whole new set of possibilities of what can be done with them.

We wanted to explore different programs for the Tello Drone, and figure out how and when they can be used in the real world. In order to research possible use cases for these DJI Tello Drones, we narrowed down three topics that we will be discussing further.

These topics include color detection and tracking, hand gesture control, and facial recognition and tracking. With exploring these three topics, this enables us to find different possibilities for DJI Tello Drone usage that is beyond simple air-bound camera work.

There are various uses for drones nowadays. Initially utilized for military objectives, they are now utilized in civilian settings. This article will examine a few possible uses for drones that are currently popular.

There are several uses for drones. They are used to deliver items, take aerial photos, and, in light of a recent development, even for consumer usage. Drone usage is permitted for both business and private purposes. Drones may be used for basic transportation as well as for mapping and photography. The most frequent query, though, concerns a drone's primary function.

Finally, the future has come. Everyone is discussing drones and how they will alter our way of life. But what precisely are drones? Why do we need them, and where did they come from?

Drones are mostly used to offer aerial views of situations that people are unable to see for themselves.

When it comes to inspecting crops, inspecting a structure that has to be renovated, or figuring out a building's plan, drones are quite helpful, as shown below.

Drone inspecting crops by taking recording and screenshots over the field

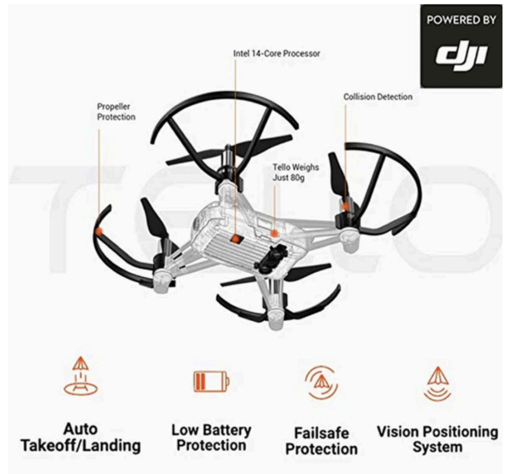
Drone figuring out plans to a building by trial and error

III. SDK USED FOR DRONE CONTROL

One of the main high-level programming languages that are useful in controlling drones would be Python and Java [5].

Within the drone's software, it can be treated as an API that can be manipulated with our control of it by being able to use higher-level languages that are more user friendly and available compared to the lower-level languages [5]. Along with the programming language, we would also need the valid Software Development Kit (SDK) necessary to program out how the drone would respond to valid commands and how it can use the Flight Controller or GPS functions to automatically proceed to a GPS waypoint. Python is easily used to control the drone since the programmer doesn't necessarily have to consider how the program is implemented at the firmware level [5]. The low-level languages that can control the drone only interact with how the firmware of the drone is coordinated with the drone's hardware elements [5].

The Tello SDK allows the user to connect the drone to a Wi-Fi UDP port, allowing it to be controlled through text commands. Accessing three different UDP ports, the drone would be allowed to achieve three separate Architecture states: receive Tello state, receive Tello video stream, and send commands and receive responses [8]. A picture of where the ports are located on the DJI Tello Drone are shown below.



The send command and receive response state must be used to initiate the Tello's SDK mode, before being able to send it all the other remaining commands.

The receiving state mode allows the server at that port to start receiving incoming state data coming from the response state [8]. The video stream of the Tello drone allows it to connect to the server at that UDP port and receive commands from the response state to start its streaming function [8].

The Software Development Kit for the Tello drone includes three basic command types: control commands, read commands, and set commands. The control commands for the SDK will return two results when a command is attempting to finish executing: "ok" if the command executes successfully or "error" if the command was unsuccessful in executing[8].

The read command of the SDK is able to return the current value of the sub-parameter(s). The set commands of the SDK will be able to set new sub-parameter values to check the current value or state of one of the drone's current qualities. As a safety feature of the SDK, if the drone does not receive any command input for 15 seconds, it will automatically land [8]. Either on the user's hand or the surface under the drone, a picture is included to demonstrate the drone landing without any input.

DJI Tello Drone auto landing to the nearest surfane, in this case the user's hand, due to not receiving any input

The control command list is as follows [8]:

- command - enter into the SDK mode.
- Takeoff - telling the Tello drone to initiate an auto takeoff procedure
- Land - telling the Tello drone to initiate an auto land procedure
- streamon/stream of - setting the drone's video stream to be on or off
- Emergency - stopping all the drone's motors immediately
- up/down/left/right x - the Tello drone will fly to that direction given a specific measurement and its distance
- forward/backward x - the Tello drone will fly forward or backward in that set distance.
- Cw x- Tello drone will rotate clockwise in the amount of degrees specified.
- Ccw x- Tello drone will rotate counterclockwise in the amount of degrees specified
- Flip x- Tello drone will be able to flip in the air mid flight depending on what direction to flip in.
- Go x y z speed - the drone will fly up to those speeds at that position
- Curve x1 y1 z1 x2 y2 z2 speed - the drone will be able to fly a curve defined by the current and two given conditions with its speed measured in cm/s/. The x, y, and z values cannot be values that are between -20 - 20 at the same time [2].

The list of read commands are a little too long, but almost all of them will give us measurement values corresponding to what is being checked so that the current height, speed, battery percentage, flight time, and temperature gives us the drone's current state as it is executing a flight pattern or to monitor its state so that accurate measurements can be made to make the determination of when it should stop or how long the drone has been active for [8].

III. COLOR DETECTION & TRACKING

For color detection and tracking using a DJI Tello Drone, a means of communicating changes in the object's position and the modification of the RGB color model values in a Python OpenCV code library[7].

To identify an object as an object, the DJI Tello Drone must be able to recognize the color of that specific object. Because RGB values chosen for any object are difficult to detect, we will stay in a specific range for the Drone to be able to recognize it with ease.

The DJI Tello Drone must also be able to detect the displacement of the object's original distance from the center of the frame and behave by adjusting that distance to be able to properly track the object[10].

For our project, it is near impossible to complete it without using software and coding to operate the DJI Tello Drone.

Not to mention, working with the hardware given presents a set of challenges where modeling with only software and running simulations would not be sufficient enough.

The issues of dying batteries and overheating are other problems we may face[4]. We must overcome this issue before the code should be tested to run commands. It should also be noted that if the battery life of the DJI Tello Drone is too low, the drone will not be allowed to take flight. Before running tests, we will charge all of the battery packs and have replacements ready on standby in case the drone will not lift off.

In addition, many times these DJI Tello Drones will overheat as well, meaning that they need a couple minutes to "breathe" so we will also bring an additional drone in the event that the other drone is still cooling down.

We later discovered another issue of the possibility where the batteries were known to be fully charged, yet the drone would not lift from the ground. This may be due to the DJI Tello Drone sensing that it is overheating. We found that launching off carpeted floors is a major issue in that the DJI Tello Drone is being prevented from cooling down[1]. However, this can be circumvented by taking off from solid surfaces such as placing a notebook, folder, or other convenient smooth and flat object under the drone as a launch surface.

By using the front camera of the DJI Tello Drone, we are required to download several libraries to be able to run the video feed of the drone with OpenCV[7]. These libraries can be found in the references.

The goal of this project is to manipulate the operation of a working drone to enable color recognition and object tracking. The internal camera streaming, stream analysis, and subsequent response will all be incorporated into the target detection process to make it more effective.

At a fundamental level, existing code repositories will be used as a reference to direct the target acquisition approach.

Such process control for target detection has several useful applications. Search and rescue operations and other humanitarian endeavors are important applications.

Operating the DJI Tello Drone with keyboard commands is an important first step to completing the goal of tracking an object[11]. The keyboard commands help the user to place the drone where he or she prefers, such as the proper height, angle, and distance from an object in a ready position for tracking[10].

The subsequent stage in color tracking is to use OpenCV to display the camera feed that the DJI Tello Drone may observe on the computer. By examining RGB values, it is possible to search the image's pixels for those that are a particular color[1]. We used several different blue values for this project. The code will blur together pixels in the blue color range that covers the most area, and it will also form a circle around the blue object that we want to track. Furthermore, other abstract colors are also available upon editing RGB values such as other abnormal colors in nature such as bright purple, orange, and pink. Abnormal RGB values are demonstrated as reference below.

The tracking of the object is done using a proportional–integral–derivative (PID) control loop incorporating the offset coordinates of the center of the object and the center of the frame. This can be done by using the coordinates from the previous frame and then comparing them to the current frame.

The goal of tracking is to track where the abnormal object is "now" based on where it was in the last frame[4].

The control loop uses the offset coordinates and the distance from the center to find velocities as well. These velocities are used to command the drone to move left, right, up, or down. It runs the loop for each frame and moves the drone accordingly. The drone should move either up, down, left, or right by observing the sign of the velocity in either the x or y directions[1].

The velocity at which the drone moves is the magnitude of the value computed by the control loop. All of this should result in a drone tracking a blue object.

Using OpenCV and the video feed from the DJI Tello Drone front camera, this code does picture recognition[7]. The desired item is assigned a range of color values, and the video stream is transformed into an array of RGB values, frame by frame. By examining the RGB values and searching for values that fall within the specified range, the position of the object is ascertained. Within the RGB range, a circle is drawn around the item, and the drone makes an effort to keep that circle in place while making flight adjustments.

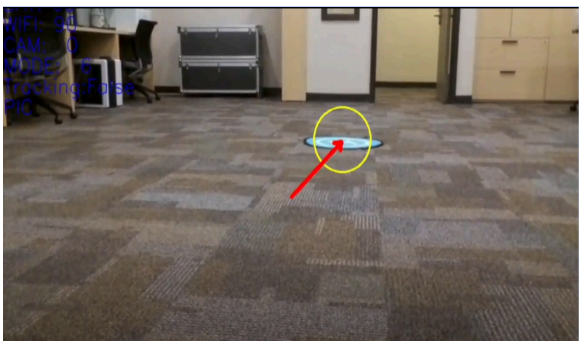
With the implementation of a PID controller and adjustment of the RGB values in the OpenCV code for any object's specific color, it is possible to reach our goal for this project, which was to enable object recognition and tracking[7].

The most efficient RGB values we found were lower bounds: [90,50,50] and upper bounds: [110,255,255]. These values will give us the best range, specifically for a blue object[2].

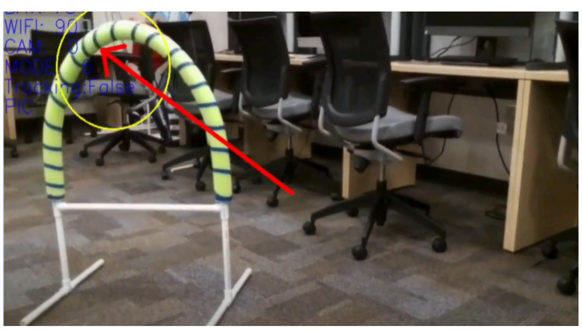
The DJI Tello Drone shall be able to recognize any blue object well. However, it is important to consider that these objects are better off not being in front of a black background or extremely bright yellow lights, as it would be hard to detect[2].

For our study, we decided to use three different colors to best match the overall many different cases of RGB values, so we decided on red, green, and blue.

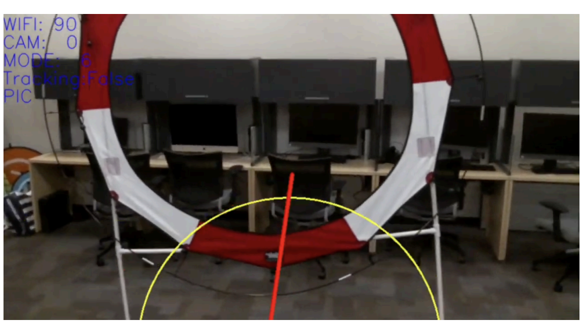
Examples of each color, red, green, and blue, will be shown in action below.



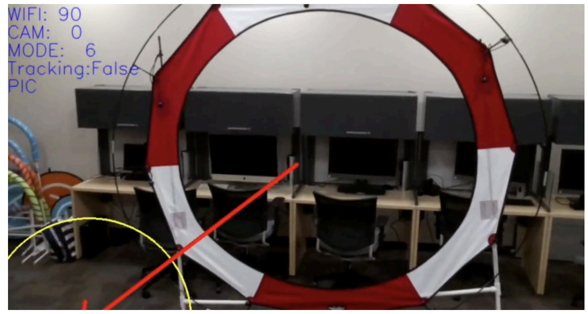
The color blue is detected



The color green is detected



The color red is detected



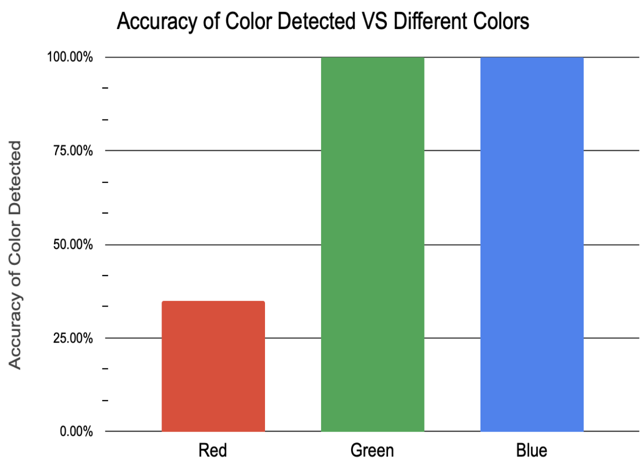
The color red is detected

With how the color recognition worked when using the Tello drone, the program read colors in RGB format as previously discussed as opposed to hexadecimal, but the ranges for very specific color ranges and color hues can be ambiguous at times, resulting in the slight bugginess of the drone's recognition process.

For example, if we look at the detection of the color red, we may notice how inefficient the DJI Tello Drone's camera is in detecting the color red. This may be quite odd, as the colors of blue and green are successfully detected by the drone.

For these issues regarding color tracking, we will generate a bar graph, shown below, that demonstrates each of the colors we have used, red, green, and blue, in that order. In addition, we have also generated a table in which displays the colors chosen for each trail, which includes red, green, and blue, as well as the number of "hits" or times it recognizes that specific color, and finally the number of misses according to each color.

Colors	Hits	Misses
Red	3	7
Green	10	0
Blue	10	0



From the results shown above, the accuracy of detecting red was effective for roughly 30% of the time and was inconsistent. For detecting the accuracy of green and blue however; both of those colors were detected and tracked 100% of the time, as testing out the capacity, effectiveness, and visual tracking of these drones.

IV. HAND GESTURE CONTROL

The next iteration of object tracking with the drone is to control the drone's command with your hand. Using the Tello Drone's API along with a machine learning platform called MediaPipe, it is possible to program the drone to execute commands based on the hand gestures it sees.

The only physical requirements are a laptop or tablet, a tello drone, and a hand [1]. MediaPipe has a Hand Keypoints detection written in Python that can return 2D coordinates of objects.

To detect a hand, it will basically identify every joint there is on one [4]. This includes the fingertips, every knuckle of every finger, and the wrist. It can also differentiate between the pointer finger, ring finger, middle finger, pinky, and thumb for even more accuracy [4]. Each joint with respect to each finger is assigned a unique value, so no confusion is made by the drone. A hand is included here as reference.

Only a few examples can achieve accuracy, because the MediaPipe framework has such robust detection capabilities. The structure is simplified for users, so using Grid Search can help a programmer find the best settings for their detection program. To avoid false detection, a gesture buffer will be created to serve as an ID to verify that the object in sight is a hand [4].

To run this part of the project, the GitHub repository must be cloned, and MediaPipe must be set up on the device that it will run on. OpenCV will also be used for image processing. After that, the usual Tello drone setup is required, which includes connecting your device to it through Wi-Fi.

A demonstration of using MediaPipe with running OpenCV from the DJI Tello Drone is shown below.

The MediaPipe setup from the drone's perspective allows it to track moving objects and follow commands using available hand gestures.

Once everything is set up, you can run the program and test out its capabilities. There are currently eight main commands executed with hand gestures.

The gesture controls are as follows [4]:

- 👆 Up - pointer finger pointing up, thumb pointing horizontally, and the rest of the fingers balled in a fist.
- 👇 Down - pointer finger pointing up, thumb pointing horizontally, and the rest of the fingers balled in a fist.
- Left - fingers are balled in a fist except for the thumb, which is pointing to the left.
- Right- fingers balled in a fist except for the thumb, which is pointing to the right.
- ✋ Forward - open hand, like a high five.
- 👊 Back - fully closed fist with knuckles facing the camera.

- 👌Land- OK symbol; pointer fingertip and thumb fingertip connected, with the rest of the fingers standing up. The wrist will be pointing sideways at the camera.
- ✊ Stop - fully closed fist with knuckles pointing to the ceiling; raised fist.

The emojis are used to give the reader a visual representation of each gesture.

The program will have the option of keyboard controls in case the gesture controls aren't working properly. To switch between the keyboard and hand gestures, just use "k" to toggle the keyboard control, and "g" to toggle the hand gesture control [4].

This part of the project may not be implemented due to its advanced nature, but its concept is very intriguing and can be explored if we finish all the other components, particularly the object tracking component, due to their similarities.

After attempting to conduct experiments using this program, we eventually came to the conclusion that this specific program only works with a specific Python version, along with specific versions of Python packages, with some being outdated. This discovery confirmed our previous suspicions of not being able to implement the hand gesture software.

Luckily, we did have fruitful results from our research on all of the other prospective programs.We also realized that there aren't many useful real-world applications using hand gesture control.

It's currently more of a recreational extension that can be added to the Tello Drone, with the accompanying working Python packages and version, of course. It can also be used as a reference point to build upon when creating other machine vision applications, like full body detection, similar to ones used in video games or movies to create Computer Generated Images.

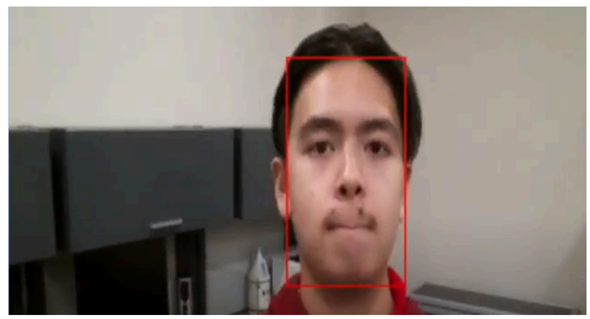
In short, there is no directly constructive use of hand gesture control for Tello Drones, but the logic behind it can be extrapolated for use in other areas.

V. FACIAL RECOGNITION & TRACKING

The last piece of software we researched was the Face Recognition and tracking software.

For this program we embarked on giving the DJI Tello Drone the ability to recognize a face from a distance of 20 feet or less, and track it as long as the subject did not swiftly move out of frame.

To be clear, this is simply facial tracking or detection, not recognition. This program does not save the data of the faces detected. It simply identifies a human face, and tracks it within its camera frame.

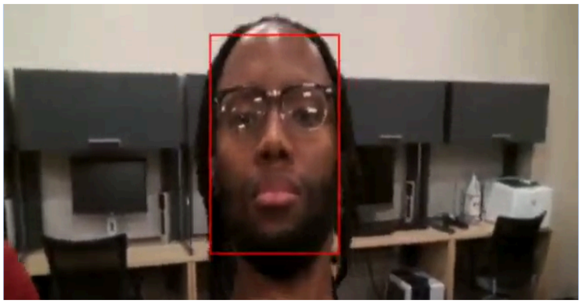


When the drone locates a face, it will fly closer until it is approximately 1 foot away from the face.

A common problem encountered with many machine vision applications is that they are unable to detect darker skin tones, limiting their service capabilities for people with those darker skin tones.

This program is capable of detecting faces of a wide spectrum of skin tones, ranging from any level of dark to light, solving a problem that has existed for years, and still persists today.

Our findings discovered no trouble tracking between lighter and darker skin tones, with immediate facial recognition. No problems regarding that occurred when using the program. An example of the program running is shown below.



No issues arose when detecting a darker skin tone

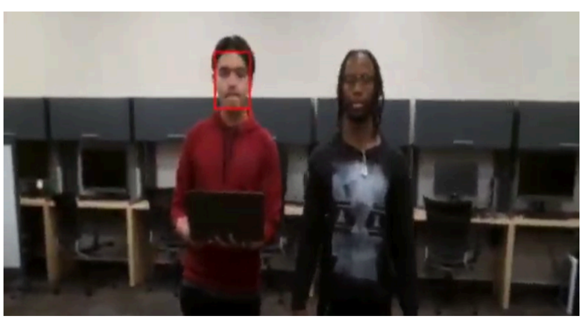
However, one problem that we did encounter was presenting two different faces in the camera frame simultaneously.

This is due to the fact that we designed the program to only track one face at a time.

This means that multiple faces within the view of the camera frame will ultimately cause some trouble, as it cannot detect more than one face.

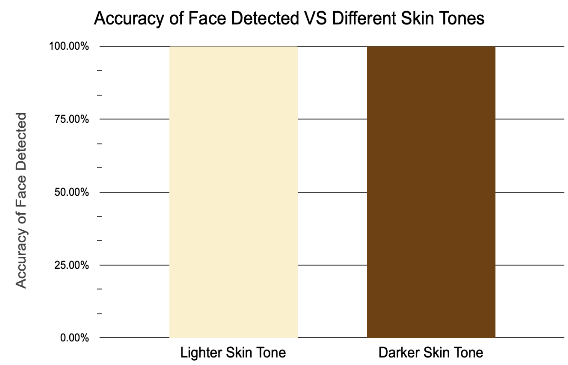
In addition, when two or more faces are simultaneously placed in the DJI Tello Drone's camera view, the drone will quickly flicker between each face before "choosing" one and focusing on that one, thus tracking it accordingly.

An example of the DJI Tello Drone trying to recognize and detect two faces of different skin tones is shown below.



When presented with two faces, it will choose one and focus on it

To clear any issues regarding facial recognition and tracking for different skin tones, lighter and darker, we have generated a bar graph, shown below, that demonstrates the accuracy of each face detected versus that of the face being either light skinned or dark skinned in that order.



From the results shown above, the accuracy of recognizing lighter skin tones was effective at 100% of the time and was quite consistent. This goes for recognizing darker skin tones as well, as the program recognized darker skin toned faces 100% of the time. It is safe to say that the facial recognition and tracking for all skin tones is effective and efficient.

In conclusion, it does not matter what color of skin the user was. The DJI Tello Drone program was able to detect and track anything as long as it was fixed as a person's face.

VI. OVERALL ISSUES & CONSTRAINTS

- The color recognition program read colors in the RGB format as opposed to hexadecimal, so the color/shade ranges could be a bit ambiguous at times, leading to confusion in the recognition process for the drone.

- Facial recognition software cannot detect two faces at a time currently.
  - If two faces are present in the camera frame, it will identify one and lock onto it, or will flicker between both.
- Tello Drones have a limited energy capacity, so flights only last up to 10 minutes before a new battery is needed. Batteries typically take around an hour to fully recharge.
- Tello's body is designed to withstand impacts as well, but the rotors are susceptible to breakage, so avoid impact with any hard objects.
- Generally, it is not recommended to control these tiny drones, as outside factors like the wind can skew the drone's flight path slightly away from its intended destination.
- Being out of the drone's range when connected to wifi prevents the user from being able to control its exact movement and losing its connection.
- Many times we found that after using the drone for a certain period of time it will overheat, preventing it from taking it off, thus we had to bring multiple DJI Tello Drones with us to complete testing and researching

VII. CONCLUSION

There exists a great many advantages with designing the DJI Tello Drone for our own purposes. Designing a superior control system allows us to make the impossible happen.

With the implementation of Tello SDK and OpenCV onto the DJI Tello Drone, it is capable of identifying abnormal objects and colors using machine vision, and will ultimately know how to behave and respond based on these objects and where they are located based on the position of the drone. Furthermore, we will take object recognition and tracking to the next level with implementing MediaPipe, a machine learning platform.

MediaPipe is designed to detect Hand Key Points. Because our hands are complex shapes, MediaPipe will identify all joints and characteristics of our hands, including our fingertips, knuckles of each finger, and the wrist, which will identify which finger is which based on these characteristics. With being able to detect each of our five fingers, this allows our algorithm to detect hand gestures and behave based on those movements.

We discovered that simple drones with cameras are able to do much more than just fly around. They are able to detect and behave at almost anything thrown at them. Drones are capable of doing the impossible and are more than likely going to help restructure our ways of life.

These programs can optimize the efficiency of numerous processes such as object filtering, providing new uses of object control with hand gestures, and saving lives by finding endangered people in natural disasters, such as floods and forest fires.

As technology advances, and more people research and discover new uses for the drones, new avenues of development will be found, and possibilities realized through use of the drone.

One of the next steps this technology can take is to become scalable for larger drones. Software is advancing at unprecedented rates today, so who knows what new function someone might find for the Tello Drone.

Drone saving someone in a flood

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