An Extended Study of the Applications of Using Gesture Control to Pilot UAVs

William Carpenter
University of Central Florida
Orlando, FL 32816
williamcarpenter989@gmail.com

Patrick Omodara
Brooklyn College
Brooklyn, NY 11210
omodara09@gmail.com

Radu Babiceanu
Embry-Riddle Aeronautical University
Daytona Beach, FL 32114
babicear@erau.edu

Laxima Niure Kandel
Embry-Riddle Aeronautical University
Daytona Beach, FL 32114
niurekal@erau.edu

***Abstract*—Unmanned Aerial Vehicles (UAVs) are normally piloted by a traditional ground controller (GRC). This paper proposes a modeling approach for gesture-based control of UAVs. While the GRC approach can be useful, there are several issues that can be improved by using only gestures. By using gesture control, users with no previous experience can instantly control an UAV at an elevated level. Because users only need gestures, UAVs can be used for more applications. Utilizing python code, gesture control was implemented on a DJI Tello drone using computer vision. The UAV camera recognizes user gestures and interprets them as written in the code. Using intuitive controls, users can use the unmanned systems in many ways and complete a wide variety of tasks. GRC signals are vulnerable to eavesdropping posing security risks. In contrast, gesture control, which relies on physical movements or hand gestures, eliminates the need for signal transmission susceptible to interception. By integrating gesture control into the authentication process, an additional layer of security can be established.**

Keywords—Unmanned Aerial Vehicles (UAV), gesture-based control, facial recognition

I. Introduction

Unmanned Aerial Vehicles (UAVs), commonly known as drones, are unmanned aircraft that do not transport people. For this reason, drones can be employed in various specific applications. They can access remote areas, monitor, and obtain high-definition imagery [1]. UAVs can efficiently and cheaply carry out tasks that would otherwise prove difficult with crewed aircraft [2]. They are also becoming more versatile and cheaper as technology improves [3]. One of the issues they pose is the complexity of piloting them. There is a significant challenge for training the massive influx of people interested in UAVs. On the bright side, more people can become pilots of drones with the use of gesture-control [4-5]. A gesture is simply moving a part of the body to express a certain meaning. There are many systems that can be controlled with only the use of gestures. The first gesture interface system was PINCH by Fakespace, using a glove and sensors to detect the hand. Other devices to assist in detecting gestures are the Xbox Kinect, Leap Motion, Nintendo Wii, and the 6th Sense Glove [6]. Artificial intelligence and computer vision make it possible to control UAVs using only gestures. Individuals with no previous experience can control a drone at an expert level by using gestures. Piloting UAVs utilizing only gestures means anyone can pilot the aircraft at a high level due to the intuitive nature of gesture control [7]. Professionals in other fields that do not have the time to control an UAV via a remote control can pilot a UAV immediately. A user can make commands such as takeoff, landing, directional inputs, follow me, and hovering with a change in hand gestures [8]. UAVs can have further applications with the addition of gesture control such as education and package delivery because of the intuitive nature of gestures. Someone can quickly learn how to pilot a drone with just using gestures and give useful commands such as "follow me" and "land" easily. This paper proposes a method of implementing gesture control for UAVs and adds more gestures to the existing library of gesture-controlled UAVs. The paper also proposes applications for UAVs that can be implemented immediately, or soon in the future as Artificial Intelligence (AI) and Machine Learning (ML) improve.

II. Related Work

The meteoric rise in the use of UAVs makes them a popular area for research. With the higher accessibility of drones and range of applications, the users do not need to be trained professionals to utilize them. This results in a need for simplified control methods so that a drone can be piloted without extensive training, which is where the alternative method of gesture control is useful [9]. The topic of controlling a drone using only gestures has been researched extensively. The control of drones using gestures is usually split into two categories, using specialized gloves, and using computer vision with the on-board camera. Instead of using buttons, the sensors in the glove recognize the gestures made and move accordingly. Computer vision employs real-time analysis, which is more convenient but can be less reliable than the use of specialized gloves. Some methods of control use external devices to detect gestures such as Leap Motion Controller and Xbox Kinect [10]. The Leap Motion Controller identifies gestures using two stereo cameras and several infrared LEDS and is used more for short distances. It can also recognize fingers at a much higher accuracy. The Xbox Kinect Sensor is more sufficient for longer distance recognition, hence detecting the body, pose of the pilot, and identifies their gestures as specific commands.

Other research has been done with gloves and other gesture methods such as voice [11]. Several works utilize deep learning for the drone to recognize gestures [12-14]. Recognizing hand gestures in real time is challenging because everyone performs hand gestures differently. The literature review identified many papers proposing applications for UAVs, but only a few of them discuss the applications of gesture-based control of drones. This work fills that gap and discusses the control of a DJI Tello drone utilizing gestures without the aid of an external device or a glove.

III. Applications

UAVs have the capability to hold the payload of a high-definition camera. The ability for UAVs to go far distances at a low cost while taking high quality photos and videos makes them in high demand in many fields [15]. Using an unmanned aircraft often saves time and money than utilizing manned aircraft. A manned aircraft requires a crew, a highly expensive aircraft such as a helicopter which takes a lot of time and has a high cost. UAVs, on the other hand, take very little time to set up, are cheap, pose lower risk, and perform a similar job. However, there is a difference in applications of a gesture-based controlled drone compared to a ground remote controlled-based drone. Remote controllers are more consistent in piloting a drone but are limited by their Wi-Fi signal [16]. Gesture-based control is more intuitive and does not require additional devices. However, gesture-based control can be less consistent. The applications shown in this section outline the main benefits of gesture-based control of drones over traditional remote controller-based drone piloting.

A. Photography

UAVs are equipped with high-definition cameras, ranging in effectiveness depending on the capabilities of the drone utilized. Drones are small, easily maneuverable, flexible, and carry these high-quality cameras. For these reasons, they replace much larger aircraft such as helicopters for cinematography [17]. UAVs are utilized in services related to photography such as film, real estate, weddings, advertising, and news [18-19]. The ability to control these devices using gestures creates more precise control. A photographer or videographer can, with no previous experience, control a drone to take whatever photos and videos they want with high precision. The process outcome may possibly be better than controlling the drone with a remote controller because gesture control can be easier and more precise. Drones create a diverse palette for photographers, from epic wide shots to precise close-ups [20]. Utilizing settings such as “follow me” that can be initialized with gestures, lets users pilot the drone without the use of constant gestures, creating many options for cinematography. The pilot can command the drone to track a certain object that can capture smooth and dynamic tracking shots, which is easily made with gestures. A powerful camera can detect someone from far away, enabling users to command gestures with commands with great precision from a long distance. Gesture control lets filmmakers create unique angles with gestures like swooping arcs, orbiting shots around an object, flips, etc. Capturing action sequences like chase scenes are much easier with gesture control due to the precise maneuverability of the commands, as well as commands such as “follow me.” This in turn creates an immersive experience for the viewer as the flow of gesture control can be more smooth than remote based control [21]. These commands provide a unique experience for photographers that would otherwise be difficult to replicate with a controller.

B. Emergency Services

UAVs have numerous applications in technical and scientific fields [22]. A particularly applicable area is wilderness rescue [23]. Current research is being done to implement gesture recognition onto a drone that is meant to search for missing persons. When the person is identified as a human being, a gesture recognition phase will commence where the drone can communicate with the person [24]. The drone can potentially drop supplies or signal directions to the person to assist in their rescue. With natural disasters occurring more frequently, search and rescue missions are becoming increasingly important. UAVs can analyze large areas of interest with a wide range of cameras. They can provide live video feed to find people of interest or disaster survivors. Drones can also assess damage, help provide medical aid, and go into hazardous places [25]. Being able to control them hands-free can be useful in situations when holding a clunky controller would be difficult, such as fires or challenging terrain. With gesture control presets, a worker in emergency services can control a UAV while performing other activities [26]. UAVs using gesture control can also carry medical supplies to remote and hazardous locations. Emergency responders who deal with extremely stressful situations can quickly understand how to control a UAV. Gesture control takes less cognitive load and attention from the user, allowing them to focus on their tasks.

C. Monitoring

UAVs have the very useful capability to monitor areas. The ability to hover lets drones monitor areas effectively, such as the borders of countries. Border patrol operations are currently using UAVs to provide air support and to monitor areas of interest. Instead of launching heavier and more expensive aircraft such as helicopters, these small drones can fit in a patrol vehicle and be put in the sky in minutes [27]. Putting on a nighttime infrared camera with high-resolution zoom on these drones can detect drug smugglers or illegal border crossings [28]. Situations in which the pilot needs to control the drone hands-free, gesture control would provide valuable benefits. For example, a drone can be controlled with simple gestures if the operator is prefixed on capturing a person of interest. The training of using these drones can also be much faster and can provide a more intuitive experience for piloting. Utilizing drones for the inspection of infrastructure improves safety. Due to the precision of drones, UAVs can inspect outdoor infrastructure like bridges, buildings, power lines, pipelines, and antenna towers [29].

High-definition cameras take images and videos to provide information on the structural integrity of objects. The precise maneuverability of gesture control could make the experience smoother and safer. Likewise, drones could go into hazardous areas that controlling aircraft with a remote controller would not allow. With infrared cameras, UAVs can also monitor wildlife. They can track animals and their habitats at a more successful rate than people [30]. With gestures, a researcher can signal to follow a certain group of animals with high precision. Likewise with gestures, drones can monitor and map coastal areas and marine ecosystems [31]. Instead of constantly switching between the drone and a remote controller, someone utilizing gesture control can concentrate on the drone itself more than someone switching between looking at the drone and a controller. A safer environment is created because the user has more situational awareness [32]. Users will also have the option to move freely and control the drone at the same time. This creates a more intuitive experience for anyone piloting a drone to monitor an area.

D. Agriculture

UAV usage is growing fast in every sector of the economy [33]. Agriculture is no exception, with the agriculture drone market worth $17.9 by 2028 [34]. From monitoring to security, the information drones help farmers. The system of precision farming utilizing drones can increase yields of crops by as much as 5% [35]. UAVs with specialized sensors can monitor the quality of air, water, and soil, and predict plant health. Drones can also provide information on pollution, wildlife, and deforestation with specialized cameras by monitoring different areas of interest [36]. Using gestures, any farmer can easily command a drone or several ones to monitor their fields. They can quickly learn how to pilot a UAV without the need for a controller and provide extra options for a user to pilot a drone. The gesture control of these drones can help in easier maneuvering of the drone [37]. UAVs can also be fitted with other payloads like insecticide to spray onto crops [38]. Attaching a thermal camera to a drone allows it to detect plant health, help with irrigation and see crop yields at an accurate level.

E. Package Delivery

Another major application of UAVs is package delivery. Amazon, a very large organization in the package delivery business, filed a patent for a delivery drone that can be controlled through speech or gestures [39]. The person receiving the package can communicate with the UAV to help guide the path to the delivery location. Gestures such as a "shooing" motion would signal the drone to move closer, while a wave of the arms suggests an instruction to deliver the package. Gesture-based control of drones simplifies the process by making it more user-friendly [40]. A user can easily gesture to a drone to deliver a package without a controller. The process does not involve physical controllers or smartphones, letting users have a hands-free experience during package delivery. People unable to physically handle a controller or smartphone can safely give and receive packages. People less comfortable with remote controls or smartphones can now be included in the package delivery process [41]. In the case of medical deliveries, when the drone arrives the emergency personnel can intuitively direct the drone to go wherever they need with great precision at minimal risk. Gesture control UAVs can also be deployed to deliver essential supplies, ammunition, and other equipment to troops on the battlefield [42].

F. Recreational Peformances

UAVs bring a unique perspective to recreational activities. With recent advancements in drone technology, UAVs can make complex shapes in the sky from a preset configuration [43]. By using hand gestures, performers can interact with digital and physical elements in an act to create lighting effects and visual projections. Gesture control of drones can create precise movements. Controlling a swarm of drones with just gestures can be an exciting experience for people [44]. With voice or body gestures, an entire swarm of drones can change shape. For example, a configuration can be made so that when a pilot makes a square shaped gesture, the swarm of drones would come into the shape of a square. Drones can have different colored lights, which can be coordinated to make light shows.

G. Education

Controlling drones without equipment creates an engaging, hands-on learning experience. Students can immediately control drones, providing engagement and an active learning environment [45]. These activities improve social skills and teamwork. Instead of instructors talking about how to pilot drones on a complicated remote controller, a student will immediately be able to pilot them by just using their hands. People that are experts in other fields do not have much time to learn how to control a drone with a remote controller. Any amateur can efficiently and safely learn how to pilot a UAV with only gestures because of their intuitive nature. The intuitive nature of gesture control of drones lets anyone with no previous experience control a drone with extreme precision [46]. Most UAVs have built obstacle avoidance systems that will detect incoming objects, assisting in errors pilots may make.

H. Military

UAVs also improve military power. One of the more popular methods of using drones in the military is for the utilization of drone strikes [47]. Soldiers can quickly learn how to control a drone with a gesture control method. Drones are used for real-time reconnaissance and surveillance of dangerous areas [48]. Facial recognition can also identify people of interest [49]. Gesture control of a swarm of UAVs can attack areas of interest and complete designated missions that would otherwise be impossible [50]. Drones can be used to counter potential improvised explosive devices with improved cameras [51]. Weapons can be attached to drones with large payload capacities [52]. A gesture controlled based drone with weapons attached can be used for various missions, such as clearing areas of interest. Situations that require soldiers to control a drone, while carrying other equipment, will benefit from the hands-free experience gesture control provides.

I. Cybersecurity of Gesture-based Controlled UAVs

Improvements in gesture-based control of UAVs add an extra layer of authentication. Remote controls and smartphones can be vulnerable to spoofing or interception attacks [53]. Gesture-based control does not use other hardware equipment besides the drone. Controlling a drone through only gestures mitigates potential cybersecurity threats because there is less equipment involved. Because the drone must be controlled in close physical proximity with only precise gestures, it would be extremely difficult for unauthorized people to gain access to the device from a remote location.

J. Artificial Intelligence and Machine Learning

As ML algorithms improve, the identification of the gestures will become much quicker, and drones will become much easier to control [54]. This will increase the potential pallet for operators to use. Improvements in gesture control using AI will allow smoother control of UAV swarms as well. A swarm of UAVs has the potential to attack and defend more systems than a single drone [55]. Improvements in AI approaches allow for a quicker and more accurate learning experience. The main issue for AI/ML is that massive amounts of data will be needed, which will take time to implement [56].

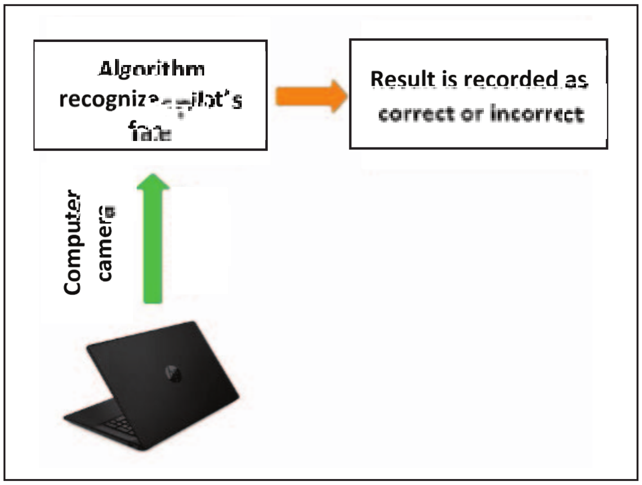


Fig. 1. Facial recognition system: controller and models.

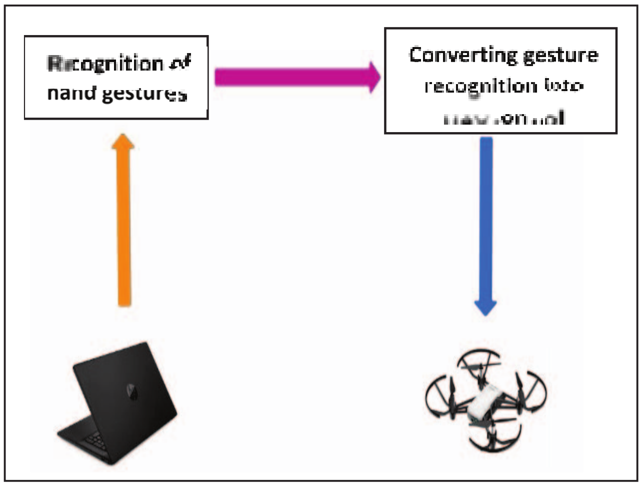


Fig. 2. Gesture-based control system: controller, UAV, and models.

IV. Implementation

The approach followed by the student team in this work consists of two components, facial recognition, and hand gesture recognition control. The two approaches are illustrated in Fig. 1 and 2, respectively. The goal of this research is to control/pilot the DJI Tello drone using gestures. The student team's research plan considered multiple gestures to enhance the experience of the user and create many options for piloting. With intuitive directional commands such as Up, Down, Left, and Right, users can easily pilot a drone. Facial recognition was trained using a deep learning module. This deep learning algorithm took hundreds of pictures to identify a person's face. Facial recognition is implemented to begin gesture control of the DJI Tello system. This provides extra security to ensure only authorized users can pilot the drone. First, we studied the existing libraries on gesture control, then we made sure it worked on our HP Computer. The Media Pipe software identifies the points on a hand and recognizes the gestures [57]. A deep learning algorithm was used for facial recognition. The algorithm has learned from hundreds of pictures of a person's face, and we implemented this algorithm onto the DJI Tello.

A. Facial Recognition Implementation

For the facial recognition code, the student team decided to use a web browser deep learning model known as Teachable machine [58]. The platform was used to train pictures of both students' faces before implementing them into the code. For each of the faces, 800 pictures were uploaded, which resulted in 1,600 pictures. The optimal amount of epochs was then set and training the model was started. The Keras file was downloaded with the model and implemented into the computer vision code. The goal of the code was to identify both student faces. Once this process is completed, the drone was ready to takeoff. The facial recognition demonstration is illustrated in Fig. 3, while a snapshot of the deep learning algorithm is shown in Fig. 4.

B. Hand Directions Regognition for Gesture Control

For gesture control, the student team decided to make the controls as intuitive as possible. The drone contains directions of Up, Down, Left, Right, Forward, Backward, and Rotate. These directions cover every angle of movement. For the Up, Down, Left, and Right movements, the thumb was used for control. If the thumb is above the Index and Middle finger, it will go the direction pointed. For Forward and Backward, the Index finger must be above the Thumb and Middle fingers.

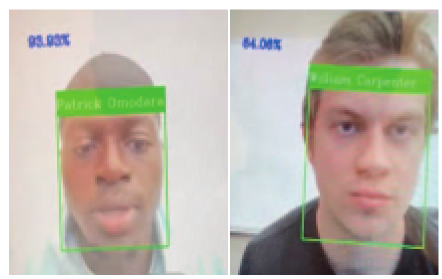
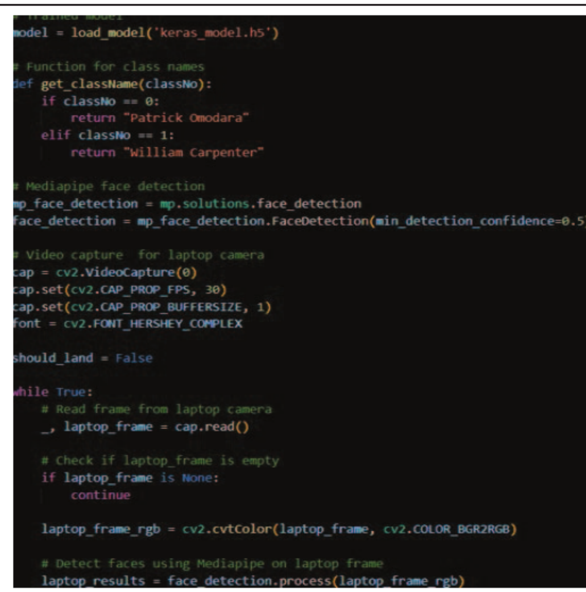


Fig. 3. Facial recognition demonstration.



```
model = load_model('keras_model.h5')

# Function for class names
def get_className(classNo):
    if classNo == 0:
        return "Patrick Omodara"
    elif classNo == 1:
        return "William Carpenter"

# Mediapipe face detection
mp_face_detection = mp.solutions.face_detection
face_detection = mp_face_detection.FaceDetection(min_detection_confidence=0.5)

# Video capture  for laptop camera
cap = cv2.VideoCapture(0)
cap.set(cv2.CAP_PROP_FPS, 30)
cap.set(cv2.CAP_PROP_BUFFERSIZE, 1)
font = cv2.FONT_HERSHEY_COMPLEX

should_land = False

while True:
    # Read frame from laptop camera
    _, laptop_frame = cap.read()

    # Check if laptop_frame is empty
    if laptop_frame is None:
        continue

    laptop_frame_rgb = cv2.cvtColor(laptop_frame, cv2.COLOR_BGR2RGB)

    # Detect faces using Mediapipe on laptop frame
    laptop_results = face_detection.process(laptop_frame_rgb)
```

Fig. 4. The deep learning model for facial recognition.

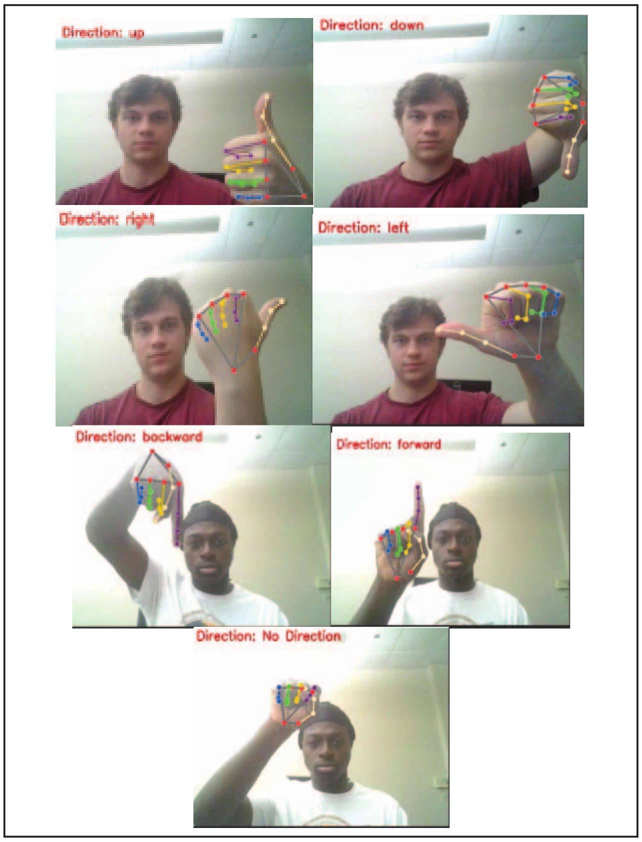


Fig. 5. Gesture-based commands for UAV system control.

When the Index finger is pointed up, the drone moves forward, and when pointed down the drone moves backwards. All these commands are illustrated in Fig. 5. Instead of standing in front of the drone to control it, the drone can be controlled from the computer with both the PC and drone cameras on. This approach allows to see not only where the drone is going but also to know if the commands are being read by the drone. There is also an option available to control the drone through its camera. A snapshot of the algorithm for gesture-based commands is shown in Fig. 6.

V. Experimental Results and Identified Challenges

The algorithmic implementation was executed on the experimental setup with the goal of recognizing faces by testing it on two people from the front angle. The algorithm was tested by evaluating the accuracy given over a period. At each marking (10s, 20s, 30s, and 40s), the accuracy was recorded. It can be seen from the results that the average recognition rate is over 85%. Table I presents the results of facial recognition algorithm over the period of study. To evaluate the performance of the algorithm for hand gesture recognition, four volunteers were identified. The volunteers had no advance training in algorithm testing. They made gestures at random, which were recorded together with their success rate. The results showed an average recognition rate of over 85%. Table II presents the accuracy of gesture control algorithm when using the experimental setup described in a previous section. The latency of the software also had an effect on the recognition of the gestures. It would occasionally take several seconds for the software to catch up, and accurately recognize the gesture being made.

```
middle_x = hand_landmarks.landmark[mp_hands.HandLandmark.MIDDLE_FINGER_TIP].x
middle_y = hand_landmarks.landmark[mp_hands.HandLandmark.MIDDLE_FINGER_TIP].y

horizontal_diff = thumb_x - index_x
vertical_diff = thumb_y - (index_y + middle_y) / 2
avg_y = (index_y + middle_y) / 2

#  Directions
# Up
if vertical_diff < -0.1:
    direction = "Up"
    tello.send_rc_control(0, 0, 20, 0)
#  Down
elif vertical_diff > 0.1:
    direction = "Down"
    tello.send_rc_control(0, 0, -20, 0)
# Right
elif horizontal_diff > 0.1:
    direction = "Right"
    tello.send_rc_control(20, 0, 0, 0)
# Left
elif horizontal_diff < -0.1:
    direction = "Left"
    tello.send_rc_control(-20, 0, 0, 0)
# Forward
elif index_y < avg_y - 0.05:
    direction = "Forward"
    tello.send_rc_control(0, 20, 0, 0)
# Backward
elif index_y > avg_y + 0.05:
    direction = "Backward"
    tello.send_rc_control(0, -20, 0, 0)
# Rotate
else:
    direction = "No Direction"
    tello.send_rc_control(0, 0, 0, 20)
```

Fig. 6. The gesture-based control commands implementation.

TABLE I. FACIAL RECOGNITION OVER TIME

Time Interval (Marking)	Face 1	Face 2
10s	89%	80%
20s	83%	93%
30s	92%	79%
40s	93%	90%

TABLE II. ACCURACY OF GESTURE COMMAND FOR UAV CONTROL

Commands	Person 1	Person 2	Person 3	Person 4
Up	100%	100%	95%	100%
Down	100%	100%	100%	100%
Left	100%	100%	90%	95%
Right	90%	100%	85%	95%
Forward	100%	85%	100%	80%
Backward	80%	75%	100%	80%
Rotate	100%	100%	100%	100%
Hover	100%	100%	100%	100%

The conclusion of these experiments is that both the facial recognition algorithm and the hand-based gesture control algorithm work to a satisfactory degree.

The main issue with the UAV gesture control is to have the camera recognize the gestures in an efficient and accurate manner. It can be difficult for the camera to correctly interpret the gestures made. One significant issue of computer vision gesture control is its reliance on the gestures to stay within the frame of the drone camera. If the drone cannot see the person making the gestures and correctly interpret them, then the drone will not be correctly flown. Another concern is related to recognizing faces when there is a certain degree between the camera and the face. Additional experiments are needed to evaluate the performance in the case of UAV camera exhibiting a certain degree of tilt in relation to the pilot face. In windy or cloudy conditions, it can be difficult for the camera to correctly recognize the gestures commands because the camera does not have a clear view. This may mean the range of gesture control can be limited depending on the camera attached to the UAV. Factors such as lighting, background, shadows, reflections, and range can also affect the reliability of gesture control.

The only gestures an unmanned system can receive are the ones already embedded within it. Pilots must understand all the gestures before flight to properly fly the drone. People also gesture differently, causing piloting of the drone to be inconsistent. For the facial recognition, it is difficult to get a completely accurate recording. The model was trained on specific pictures. If the tests are not related to those specific pictures, it could be difficult for the algorithm to recognize the faces. Another issue is training the actual algorithm. To train the algorithm it takes a massive amount of data. The exact amount of data needed is unclear, but it must not be too much or too little, otherwise the algorithm cannot be trained properly.

VI. Conclusions and Future Work

In this paper, a method of gesture detection and control was proposed to pilot a UAV. A method of implementing facial recognition onto a drone was also proposed. Current and future applications of gesture control were also discussed. This framework was proposed to provide an additional solution of controlling a drone using gestures. This work successfully implemented facial recognition and hand-based gesture control onto a DJI Tello by utilizing computer vision.

The applications of the gesture control of UAVs are vast and ever expanding. With advancements in AI/ML domain, the drones of the future will have better recognition and interpretation of gestures enabling even more precise control of UAVs. Future work will be conducted on adapting gesture control of drones into different sectors. More research is needed in the AI/ML domain and the application to UAV control. Advanced ML research would allow more gestures to be recognized accurately. It would also allow for a more intuitive experience so anyone learning to fly a drone with gestures could do so immediately. Some sectors of the economy such as agriculture, package delivery and wilderness rescue are in the early steps of utilizing gesture control onto their drones, but the technology needs to improve to make it more accurate and applicable method of control.

Acknowledgment

This material is based upon work supported by the National Science Foundation award CNS-2244515.

References

[1] Y.-H. Ho, and Y.-J. Tsai, “Open collaborative platform for multi-drones to support search and rescue operations,” *Drones*, vol. 6, no. 5, pp. 132, 2022. doi:10.3390/drones6050132.

[2] J. Davis, “CBP Small Drones Program,” U.S. Customs and Border Protection, https://www.cbp.gov/frontline/cbp-small-drones-program#:~:text=Drones%20provide%20Border%20Patrol%20agents,in%20a%20matter%20of%20minutes (accessed Jul. 19, 2023).

[3] A. Otto, N. Agatz, J. Campbell, B. Golden, and E. Pesch, “Optimization approaches for civil applications of UAV or aerial drones: A survey,” *Networks*, vol. 72, no. 4, pp. 411–458, 2018. doi:10.1002/net.21818.

[4] V. Tangermann, “This system lets you fly a drone with arm gestures,” Futurism, https://futurism.com/the-byte/fly-drone-arm-gestures (accessed Jul. 24, 2023).

[5] A. Sarkar, K. A. Patel, R. K. Ganesh Ram, and G. K. Capoor, “Gesture control of drone using a motion controller,” *Int’l Conf. Industrial Informatics & Computer Syst.*, 2016. doi:10.1109/iccsii.2016.7462401.

[6] T. Krakowsky, “A very, very brief history of gestural interfaces,” Ad Age, https://adage.com/article/on-design/a-history-gestural-interfaces/139976 (accessed Jul. 19, 2023).

[7] Y. Yu, X. Wang, Z. Zhong, and Y. Zhang, “Ros-based UAV control using hand gesture recognition,” *29th Chinese Control and Decision Conference*, 2017. doi:10.1109/ccdc.2017.7978402.

[8] D. V. Redrovan, and D. Kim, “Hand gestures recognition using machine learning for control of multiple quadrotors,” *IEEE Sensors Applications Symposium*, 2018. doi:10.1109/sas.2018.8336782.

[9] K. Konstantoudakis, K. Chrstaki, D. Tsiakmakis, D. Sainidis, G. Albanis, A. Dimou, and P. Daras, “Drone control in air: An intuitive system for single-handed gesture control, drone tracking, and contextualized camera feed visualization in augmented reality,” *Drones*, vol. 6, no. 2, p. 43, 2022. doi:10.3390/drones6020043.

[10] K. Natarajan, T.-H. D. Nguyen, and M. Mete, “Hand gesture controlled drones: An open source library,” *1st Int’l Conf. on Data Intelligence and Security*, 2018. doi:10.1109/icdis.2018.00035.

[11] A. Zhou, L. Han, and Y. Meng, “Multimodal control of UAV based on gesture, eye movement and voice interaction,” *Lecture Notes in Electrical Eng.*, pp. 3765–3774, 2023. doi:10.1007/978-981-19-6613-2_366.

[12] D. Mali, A. Kamble, S. Gogate, and J. Sisodia, “Hand gestures recognition using inertial sensors through deep learning,” *12th Int’l Conf. on Computing Communication and Networking Technologies*, 2021. doi:10.1109/icccnt51525.2021.9579829.

[13] C. Liu and T. Szirányi, “Gesture recognition for UAV-based rescue operation based on Deep Learning,” *Proc. Int’l Conf. Image Processing and Vision Engineering*, 2021. doi:10.5220/0010522001800187.

[14] B. Hu, and J. Wang, “Deep learning based hand gesture recognition and UAV flight controls,” *24th Int’l Conf. on Automation and Computing*, 2018. doi:10.23919/iconac.2018.8748953.

[15] H. Nawaz, H. M. Ali, and S.-R. Massan, Applications of unmanned aerial vehicles: A review – researchgate, https://www.researchgate.net/publication/336847887_Applications_of_unmanned_aerial_vehicles_a_review (accessed Jul. 19, 2023).

[16] M. Yoo, Y. Na, H. Song, G. Kim, J. Yun, S. Kim, C. Moon, and K. Jo., “Motion estimation and hand gesture recognition-based human-UAV interaction approach in real time,” Sensors, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9002368/ (accessed Jul. 24, 2023).

[17] J. Davis, “CBP Small Drones Program,” U.S. Customs and Border Protection, https://www.cbp.gov/frontline/cbp-small-drones-program#:~:text=Drones%20provide%20Border%20Patrol%20agents,in%20a%20matter%20of%20minutes (accessed Jul. 19, 2023).

[18] S. Pagliari, “Using drones for real estate: Benefits, use cases and ROI,” DART drones, https://www.dartdrones.com/drones-for-real-estate/ (accessed Jul. 19, 2023).

[19] I. Singh, “What is drone journalism? How are drones changing news reporting?,” Drone DJ, https://dronedj.com/2021/05/03/drone-journalism-101/ (accessed Jul. 19, 2023).

[20] A. Coleman, “Best photography drones available today: Top 5 tested,” Photography Life, https://photographylife.com/best-drones (accessed Jul.

19, 2023).

[21] C. Smith, "How drones are used in photography and Cinematography," Adorama, https://www.adorama.com/alc/drones-in-cinematography-photography/ (accessed Jul. 19, 2023).

[22] C. Gaffey, and A. Bhardwaj, "Applications of unmanned aerial vehicles in cryosphere: Latest advances and prospects," *Remote Sensing*, vol. 12, no. 6, p. 948, 2020. doi:10.3390/rs12060948.

[23] J. N. McRae, C. J. Gay, B. M. Nielsen, and A. P. Hunt, "Using an unmanned aircraft system (drone) to conduct a complex high altitude search and rescue operation: A case study," *Wilderness & Environmental Medicine*, vol. 30, no. 3, pp. 287–290, 2019. doi:10.1016/j.wem.2019.03.004.

[24] C. Liu, and T. Szirányi, "Real-time human detection and gesture recognition for on-board UAV rescue," *Sensors*, vol. 21, no. 6, p. 2180, 2021. doi:10.3390/s21062180.

[25] S. Mayer, L. Lischke, and P. W. Wozniak, "Drones for Search and Rescue," *Hal*, May 2019. https://hal.science/hal-02128385/.

[26] K. Konstantinos, G. Albanis, E. Christakis, N. Zioulis, A. Dimou, D. Zarpalas, and P. Daras, "Single-handed gesture UAV control for first responders - A usability and performance user study," http://idl.iscram.org/files/konstantinoskonstantoudakis/2020/2285_KonstantinosKonstantoudakis_etal2020.pdf (accessed Jul. 24, 2023).

[27] J. Davis, "CBP Small Drones Program," U.S. Customs and Border Protection, https://www.cbp.gov/frontline/cbp-small-drones-program (accessed Jul. 19, 2023).

[28] D. Marketing, "The impact of drones on Border Security: Dedrone Solutions and the U.S. border," Drone Detection Technology by Dedrone, https://www.dedrone.com/blog/the-impact-of-drones-on-border-security-dedrone-solutions-and-the-u-s-border (accessed Jul. 19, 2023).

[29] J. A. Besada, L. Bergesio, I. Camana, D. Vaquero-Melchor, J. Lopez-Araquistain, A. M. Bernados, and J. R. Casar, "Drone mission definition and implementation for automated infrastructure inspection using airborne sensors," *Sensors*, vol. 18, no. 4, p. 1170, 2018. doi:10.3390/s18041170.

[30] J. C. Hodgson, R. Mott. S.Baylis, T. T. Pham, S. Wotherspoon, A. D. Kilpatrick, R. R. Degaran, I. Reid, A. Tersudis, and L. P. Koh, "Drones count wildlife more accurately and precisely than humans," *Methods in Ecology and Evolution*, vol. 9, no. 5, pp. 1160–1167, 2018. doi:10.1111/2041-210x.12974.

[31] K. E. Joyce, K. C. Fickas, and M. Kalamandeen, Review: The unique value proposition for using drones to map coastal ecosystems — R1/PR7, 2022. doi:10.1017/cft.2022.7.pr7.

[32] N. Gio, R. Brisco, and T. Vuletic, "Control of a drone with body gestures," *Proceedings of the Design Society*, vol. 1, pp. 761–770, 2021. doi:10.1017/pds.2021.76.

[33] I. Intelligence, "Drone market outlook in 2023: Industry growth trends and forecast," Insider Intelligence, https://www.insiderintelligence.com/insights/drone-industry-analysis-market-trends-growth-forecasts/ (accessed Jul. 19, 2023).

[34] A. Mehra, "Agriculture drones market worth $17.9 billion by 2028, at a CAGR of 31.5% from 2023," SBWire, http://www.sbwire.com/press-releases/agriculture-drones-market-worth-179-billion-by-2028-at-a-cagr-of-315-from-2023-1375472.htm (accessed Jul. 19, 2023).

[35] A. Weigel, "Drone intelligence solutions for agriculture: Aerial vantage us," Aerial Vantage, https://aerialvantage.us/drone-intelligence-solutions-for-agriculture/ (accessed Jul. 19, 2023).

[36] J. Barbedo, "A review on the use of unmanned aerial vehicles and imaging sensors for monitoring and assessing plant stresses," *Drones*, vol. 3, no. 2, p. 40, 2019. doi:10.3390/drones3020040.

[37] K. Das, R. Moganaselvan, T. Bharathmaran, and S. Marirajan, "Gesture Controlled Drone for Agricultural Assistance," *Int'l Research Journal of Eng. and Tech.* https://www.irjet.net/archives/V6/i3/IRJEt-V6I3579.pdf.

[38] G. P. Borikar, C. Gharat, and S. R. Deshmukh, "Application of drone systems for spraying pesticides in advanced agriculture: A Review," *IOP Conference Series: Materials Science and Engineering*, vol. 1259, no. 1, 2022. doi:10.1088/1757-899x/1259/1/012015.

[39] T. Ong, "Amazon's latest patent is a delivery drone that understands when you shout at it," The Verge, https://www.theverge.com/2018/3/22/17150868/amazon-drone-patent-delivery-wave-speech-recognition (accessed Jul. 19, 2023).

[40] H. Shaban, "Amazon is issued patent for delivery drones that can react to screaming voices, flailing arms," The Washington Post, https://www.washingtonpost.com/news/the-switch/wp/2018/03/22/amazon-issued-patent-for-delivery-drones-that-can-react-to-screaming-flailing-arms/ (accessed Jul. 19, 2023).

[41] A. Staff, "Amazon prime air prepares for drone deliveries," US About Amazon, https://www.aboutamazon.com/news/transportation/amazon-prime-air-prepares-for-drone-deliveries (accessed Jul. 19, 2023).

[42] M. O. Baloola, F. Ibrahim, and M. S. Mohktar, "Optimization of medication delivery drone with IOT-guidance landing system based on direction and intensity of light," *Sensors*, vol. 22, no. 11, 2022. doi:10.3390/s22114272.

[43] R. Boss, "Drone light show: Professional drone light shows and events," Sky Elements, https://skyelementsdrones.com/ (accessed Jul. 19, 2023).

[44] V. Serpiva, E. Karmanova, A. Fedoseev, S. Perminov, and D. Tsetserukou, "Dronepaint: Swarm light painting with DNN-based gesture recognition," *Special Interest Group on Computer Graphics and Interactive Techniques Conf.*, 2021. doi:10.1145/3450550.3465349.

[45] A. Verweij, "Drones in K-12 education," EDGEucating, https://edgeucating.com/drones-in-k-12-education/ (accessed Jul. 19, 2023).

[46] R. Ribeiro *et al.*, "Gesture based alternative to control recreational UAV," *Advances in Intelligent Systems and Computing*, pp. 34–44, 2019. doi:10.1007/978-3-030-16184-2_4.

[47] G. Udeanu, A. Dobrescu, and M. Oltean, "Unmanned aerial vehicle in military operations," *Scienyific Research and Education in the Air Force*, vol. 18, no. 1, pp. 199–206, 2016. doi:10.19062/2247-3173.2016.18.1.26.

[48] C. Werner, "11 ways police departments are using drones," Police1, https://www.police1.com/police-products/police-drones/articles/11-ways-police-departments-are-using-drones-V8RZTGOKMjTbWj9Z/ (accessed Jul. 19, 2023).

[49] S. Brodsky, "The Air Force's drones can now recognize faces," Popular Mechanics, https://www.popularmechanics.com/military/a43064899/air-force-drones-facial-recognition/ (accessed Jul. 19, 2023).

[50] A. Baza, A. Gupta, E. Dorzhieva, A. Fedoseev, and D. Tsetserukou, "Swarman: Anthropomorphic swarm of drones avatar with body tracking and deep learning-based gesture recognition," *IEEE Int'l Conf. Systems, Man, and Cybernetics*, 2022. doi:10.1109/smc53654.2022.9945537.

[51] V. Voronkov, United Nations Office of Counter-Terrorism, https://www.un.org/counterterrorism/sites/www.un.org.counterterrorism/files/211006_usg_opening_remarks-egm_vulnerable_targets_and_uas.pdf (accessed Jul. 19, 2023).

[52] K. Dilanian, "Kamikaze drones: A new weapon brings power and peril to the U.S. military," https://www.nbcnews.com/news/military/kamikaze-drones-new-weapon-brings-power-peril-u-s-military-n1285415 (accessed Jul. 19, 2023).

[53] J. Cole, "How to hack a drone," Discovery of Tech, https://discoveryoftech.com/how-to-hack-a-drone/#:~:text=it%20down%20entirely.-,Is%20It%20Possible%20To%20Take%20Over%20A%20Drone%3F,to%20take%20over%20the%20drone (accessed Jul. 19, 2023).

[54] M. Soori, B. Arezoo, and R. Dastres, "Artificial Intelligence, Machine Learning and deep learning in advanced robotics, a review," *Cognitive Robotics*, vol. 3, pp. 54–70, 2023. doi:10.1016/j.cogr.2023.04.001.

[55] R. Bridley, and S. Pastor, "Military drone swarms and the options to combat them," Small Wars Journal, https://smallwarsjournal.com/jrnl/art/military-drone-swarms-and-options-combat-them (accessed Jul. 19, 2023).

[56] J. Brownlee, "Impact of dataset size on Deep Learning Model Skill and performance estimates," https://machinelearningmastery.com/impact-of-dataset-size-on-deep-learning-model-skill-and-performance-estimates/ (accessed Jul. 19, 2023).

[57] MediaPipe, https://developers.google.com/mediapipe/solutions (accessed Oct. 5, 2023).

[58] Teachable Machine, https://teachablemachine.withgoogle.com/v1/ (accessed Oct. 5, 2023).