ISSUES ON QUADCOPTER DESIGN CUSTOMIZED FOR URBAN AERIAL SURVEILLANCE

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DOI: 10.19062/1842-9238.2022.20.2.2

Abstract: *The topic of this paper is in line with the efforts to reduce the spread of the pandemic effects; the objective is to design a quadcopter meant to perform urban aerial surveillance, focused on monitoring the urban traffic of cars and monitoring the traffic of groups of people, who should not gather in groups larger than three persons. The specificity of the work is given by the requirements of the European Project Semester EPS, where international teams of students actively experience a multidisciplinary and multicultural project for one semester in another university. This opportunity has allowed them to develop research and industrial partnerships. To this purpose, the approach provided by the I.N.C.A.S. as Research Partner is oriented towards Problem Based Learning and Project Organized Learning. The University as Organizer provides Project Related Courses and complementary Project Organized Learning. The research was oriented towards the customized design of a drone able to efficiently achieve the objective. The benefits of the research project are related mainly to the potential applications of the drone, with a good effect to cost ratio and to allowing the students to subsequently acquire valuable professional knowledge and experience from this research project.*

Key words: *Quadcopter, design, urban aerial surveillance, mobile/ car and people group traffic monitoring, Problem Based Learning, Project Organized Learning.*

1. INTRODUCTION

The present paper presents the study of the possibility of using drones as part of the COVID-19 lockdown monitoring system. Quadcopters had to be assessed in order to motorize crowds of people and enforcing safety requirement. The present city surveillance system was also studied and assessed. Possibilities of using quadcopter for achieving city surveillance were depicted and legal aspect was highlighted.

Afterward, computer vision and its application on Unmanned Aerial Vehicle's (UAV) for people counting were presented.

Two types of quadcopters can be distinguished: public and professional quadcopters.

Table 1 – Public and professional drones

Type	Public	Professional
Control	Remote/Smartphone Autopilot	Remote Autopilot
Price	Dozens of euros	Thousands of euros

In the last decades, quadcopters were mainly used by the military for reconnaissance and surveillance of dangerous areas or groups of people. But nowadays, they are very useful during lockdown situations [3], [4].

-study of lockdown's influence on global warming and air pollution measurement;

-give assistance or prevent emergencies;

-remind people of the exit instructions;

-monitor stores and vehicles.

Experimentation with people recognition using YOLO algorithm proved the ease of employing it. Studying the portfolio of available quadcopters on the market and making a requirement table lead to choosing the best UAV to monitor people in the street. Subsequently, an application case of city surveillance was made in Drumul Taberei, Bucharest, Romania. Deployment of the monitoring system has been studied. A MATLAB simulation of an UAV evolving in Drumul Taberei area and simulating people counting and detection allowed to experiment on the system.

A Quadcopter is a small flying object that has four arms, belonging to the UAV category. It is commonly also called "multirotor helicopter" because it is composed of four propellers allowing the Quadcopter to be vertically lifted. Quadcopters use the same physical phenomenon as helicopters which is the thrust as shown in Fig. 1.

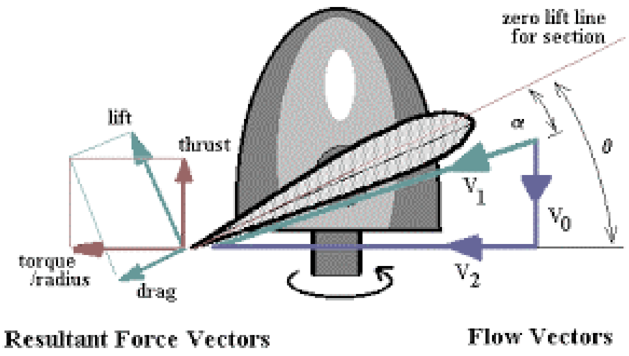

FIG. 1 – The thrust analysis of a propeller

In addition to thrust, Quadcopters use two clockwise and two counterclockwise propellers to achieve the three basic movements: Go forward, back, left, right / Turn left, right / Take off, land as illustrated in Fig. 2.

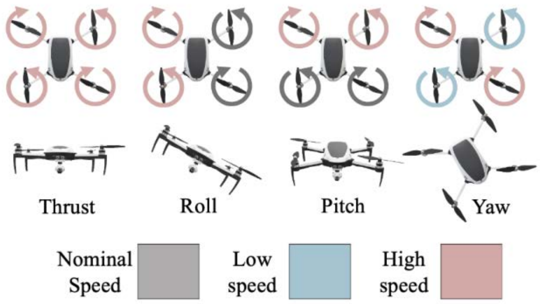

FIG. 2 The possible movements of a quadcopter

2. METHODOLOGY

2.1 Building the model

The first thing in order to create a model of the drone it is needed a block diagram to recreate the whole system. The simplest version of the system would be the one shown in Fig. 3.

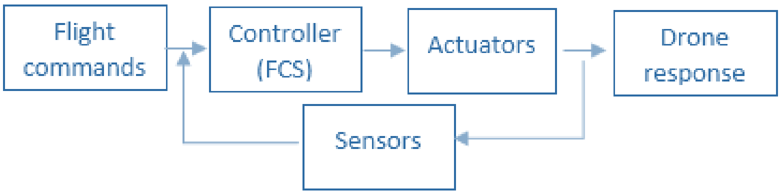

FIG. 3 Block diagram of a drone as a system

Thanks to Simulink this can be modelled into MATLAB using very similar diagrams and then include all the calculation blocks inside of them. This is illustrated in Fig. 4.

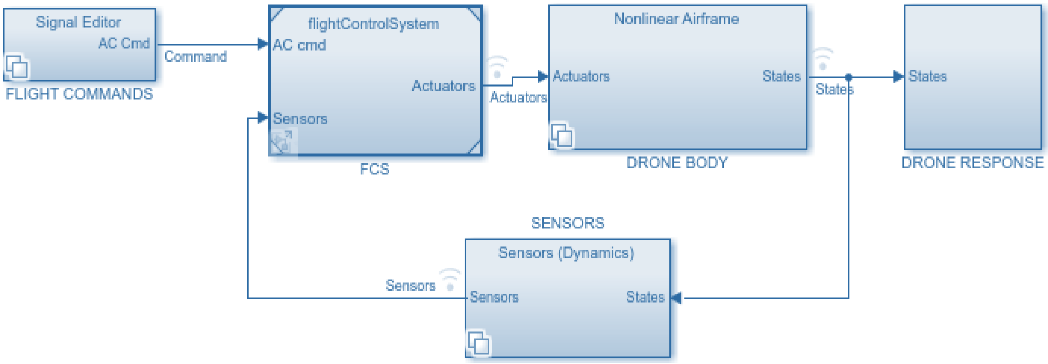

FIG. 4 Simplified Simulink model [8]

The flight commands are grouped in a block and include the pre-set settings, flight navigation paths or could represent just the remote controller of the quadcopter. That is the input for the closed loop.

The flight control system (FCS), also known as controller, it is the heart of the system. At this level, all Proportional-Integral-Derivative controller (PID) adjust the behaviour of the drone if needed and control all the actuators to ensure that the response of the system is as accurate and smooth as possible. This block also receives the feedback of the sensor to compare the actual flight parameters to the reference ones set in the flight commands block.

The drone actuators are the **4** four motors of the propellers, which receive the signal from the controller depending on the action needed (if needed).

The drone response represents the actual output of the system. Basically, it is what the drone is doing. In Simulink this block includes the 3D representation of the quadcopter.

Along with the controller, the sensor is one of the most important elements of the system. It acts as the feedback, providing the actual situation to the FCS in order to obtain the most accurate response.

Summing up, the close loop formed by the FCS, actuators and the sensors, are the ones processing the input in order to get the output as close as possible to the instructions given.

2.2 Simulation Validation and Limits

A simulation is a duplication of a real-world scenario, using a computer. This process of mathematical modeling is used to foretell the behavior or the consequence of the studied scenario. Simulations are extremely helpful for different reasons. For example, drone behaviors can be simulated without the need to operate or to have access to a real drone. Other notable reasons for the prevalent usage of computer aided simulations are as follows:

- simulations involve lower costs and are done way faster than real world experiments;
- simulations are very flexible, any input or variable can be changed easily;
- everything can be done without harming the environment or the persons involved.

The limits of a simulation are basically it's downsides or disadvantages. Most of these refer to the human operator. The main disadvantages of simulations are:

- very high processing power needed for complex models;
- building a model needs experience and special training;
- difficulties in interpretation of the result might appear;
- any error in the model or the inputs can propagate in a wrong result.

A Sense and Avoid algorithm is illustrated by A. Strobel and M. Schwarzbach [9] ,,with upsides and downsides of the approach". The result of the simulation was that once anything enters the "Threat Region", the map turns red and an avoidance maneuver begins. As a conclusion, the two limitations of this approach were that it only works with a single object entering the "Threat Region", with the other one being that even a single intruder has to maintain a constant speed and execute simple maneuvers in order for the algorithm to work properly

The main steps of achieving a good simulation:

1) Gathering accurate data that reflects the real world. (i.e.: equations or forces involved)
2) Creating algorithms (mathematical formulas) that can further generate data from what has been inputted
3) Generating ways to display the outcome (output): graphs, animations, etc.
4) Verify and validate results.

2.3 Obstacle Detection

Midair collision avoidance is a critical task that is mandatory to guaranty a safe airspace. Nowadays, airborne systems and ground systems participate in this collision avoidance for aviation. With the fast development of drones and quadcopters as depicted in [1], more quadcopters are sharing the airspace. To be able to fully use UAVs at their maximum capacities and keep airspace safe [10], the next challenge is to be able to develop a reliable collision avoidance system for UAVs. This question was already studied 20 years ago [11] but still as no answer today for the full portfolio of existing and yet to come UAV's.

The small unmanned aerial vehicles need to be visible [12] for all users of the airspace but also to be able to seek their surrounding in order to perform an avoidance if needed.

All algorithm work on the same principle Figure . They are based on deep learning and there for huge quantities of data are required to train the model. However, they can easily be trained for specific purpose, for instance, detecting people from a quadcopter. The only requirement is having a huge quantity of accurate data. Comparison of Region-based Convolutional Neural Networks (R-CNN), Faster R-CNN, You Only Look Once (YOLO) and Single Shot Detector (SSD) were conducted on different data set [5].

YOLO method was chosen because it's one of the fastest methods (it allows 30 images per seconds on a high-end computer) and pretrained models are available for experimentation.

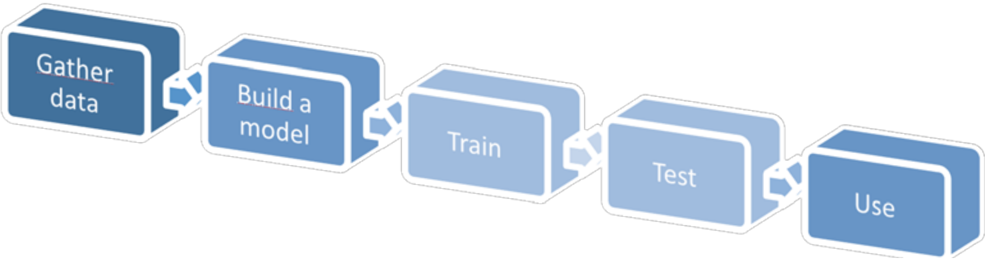

FIG. 5 Principle of deep learning

3. RESULTS

YOLO is composed of one model and a set of weights obtained from training the model on a dataset. Many models and sets of weights trained on different dataset are available. Tiny YOLO was used for experimentation as it is faster and works fine on a Computer Processing Unit (CPU). Set of weights is only 44Mo as for YOLOV3, weights are 252Mo. Tiny YOLO model is much simpler therefor the results are far below YOLOV3 capacities.

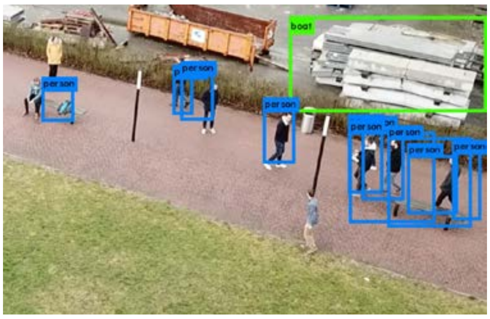

FIG. 6 Prediction on people from behind and from one side, case # 1

Data provide from two different dataset realized for studying computer vision for quadcopters. One dataset [8] is a video taken within an institute and shows people walking next to grass. The other [9] is a set of pictures taken from quadcopters in various areas, showing people and cars, Fig. 6 and 7.

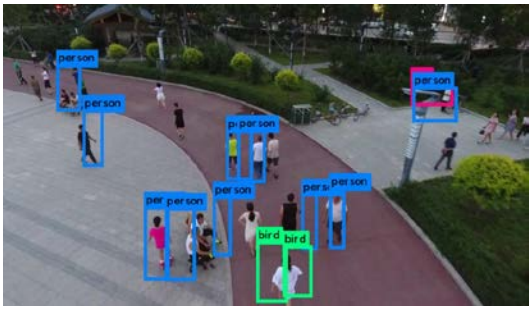

FIG. 7 Prediction on people from behind and from one side, case # 2

Experimentation highlights the limits of computer vision from quadcopter without a proper trained model. The many angles and point of views that provide quadcopter make images harder to analyze with common models. To increase people detection rate, fitting the model with a good dataset is required.

Experimentations are based on picture analysis. A video is just a set of pictures. Taking this into account, for performing real time analysis the same technique can be used. A Graphic Processing Unit (GPU) such as Nvidia GTX1080TI is required as it dedicated to the job with more processing cores. According to [7] YOLOV3 perform 45 images per seconds analysis while running on a Titan X GPU (Titan X is a high end GPU released in 2016).

Video analysis can be performed onboard, but the system is energy-consuming, so it impacts quadcopter performances. Moreover, small GPUs are expensive. The best option is to perform the analysis on the ground. Quadcopter's video feed can be sent to a ground unit and object detection is to be run there. Human operator is notified when a forbidden behavior is detected, and afterwards the operator can take the control of the quadcopter to analyze the situation, as sown in Fig. 8.

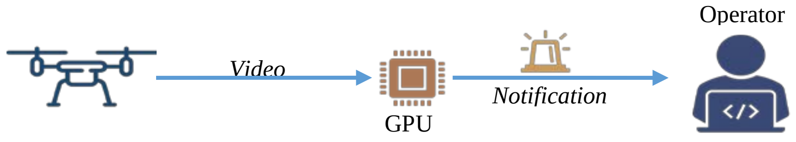

FIG. 8 Live video analysis and operator notification workflow

After detecting people on frame, the next step is to be able to measure if safety distance are respected. As the quadcopter position is not always the same, a ground projection can be done and analysis afterward. The society dragonfly has been chosen by U.S. government to develop pandemic drones with such abilities [10]. The main concern about such usage of technology is about people privacy and public acceptence. A lot of people are showing there objection to such usage. The society also claimed being able to detect people coughing, sneezing and even measure heartbeat.

Another application of computer vision to COVID-19 is mask detection. Computer vision expert Adrian Rosebrock [11] has been able to train a model that recognize if someone is wearing a mask or no. He released a tutorial on the 4th May 2020.

This fast reaction emphasize how quadcopters with computer vision capabilities can be versatile and perform many different tasks.

Different applications can be made of quadcopters with computer vision capabilities. This system can be used to analyze where population is taking risks and reinforcing security after analyzing. But also, it can be used to enforce law and to give fines by using face recognition algorithm or sending police to the place where restrictions are not respected.

In computer vision, HD cameras are usually used to captures the iamges. But different kind and sensors can be applied. The model used and the training methods differ, however, the principle stays the same. Good acquisition device and high-quality products are the keys to enable reproducible analysis.

3.1. Components

Sensors: - Ultrasonic

As the name indicates, ultrasonic sensors measure distance by using ultrasonic waves. The senor head emits an ultrasonic wave and receive the waves reflected from the obstacle. It measures the distance between the emitter and the obstacle by calculating with the time spends between emission and reception, and the sonic speed.

- Infrared

Infrared sensor is a simple electronic device, which emits and detects IR radiation in order to find out certain objects/obstacles in its range. Some of its features are heat and motion sensing. It is used in a wavelength between 0.75 to 1000µm, which falls between visible and microwave regions of electromagnetic spectrum. There are three categories: near infrared - 0.75µm to 3 µm, mid infrared - 3 µm to 6 µm, up far infrared – > 6 µm.

Mm wave is an extremely valuable sensing technology for detection of objects and providing the range, velocity and angle of these objects. It is a contactless technology, which operates in the spectrum between 30GHz and 300GHz. Due to the technology's use of small wavelengths it can provide sub-mm range accuracy and is able to penetrate certain materials such as plastic, drywall, clothing, and is impervious to environmental conditions such as rain, fog, dust and snow. TI has two families of mm Wave sensors, AWR mm Wave sensors for automotive and IWR mm Wave sensors for industrial, drones and medical applications.

Light Detection and Ranging (LiDAR) sensors use light energy, emitted from a laser, to scan the ground and measure variable distances. The result is a rich set of elevation data that can be used to produce high-resolution maps and 3D models of natural and manufactured objects.

The key features of HD for video surveillance are: Maximum HD resolution is 2.1MP, maximum megapixel resolution is 20MP or more with 5MP cameras are common from numerous vendors, HD video format is 1280 x 720 or 1920 x 1080 (megapixel cameras can offer many more formats), HD aspect ratio is 16:9 (compared to 5:4 or 4:3 in other surveillance cameras), HD frame rate is 30/25 (where megapixel cameras are often 3 - 15 frames), HDTV has quality compliance standards (where megapixel simply specifies the number of pixels)

In addition to the terrestrial forces, as a support for surveillance, aerial methods are normally used by security forces. The most common method used until now, is the helicopter, which has a relatively high operational cost [12]. This type of aircraft also has the limitations of flight altitude, large area to take off and landing or high cost among other disadvantages. Due to its large size and levels of noise, helicopter cannot fly at low altitudes above the people while an UAV can fly closer, respecting always the legal distances. Besides the altitude restrictions, for the task of taking off or landing, a helicopter needs around two hundred square meters [13] while a quadcopter can easily take off in less than one. Moreover, transporting an unmanned quadcopter from one area to another is considerably cheap. Since the drone can be carried in any kind of transport easily, while a helicopter normally flies from A to B, having a greater cost. These reasons along with the lower operator risk of an unmanned vehicle, have made it an ideal resource in the field of aerial surveillance. It is the brain of the Quadcopter. It pilots the Quadcopter. We can see two components: a flight controller (FC, in red on Fig. 31) and a Global Positioning System (GPS, in blue on Fig. 9). Equipped with sensors, the FC is the link between the pilot and the Quadcopter. It analyses the commands send by the pilot to control the speed of the rotors via the ESC. In addition, the GPS localizes the position of the Quadcopter to help it to follow a defined path.

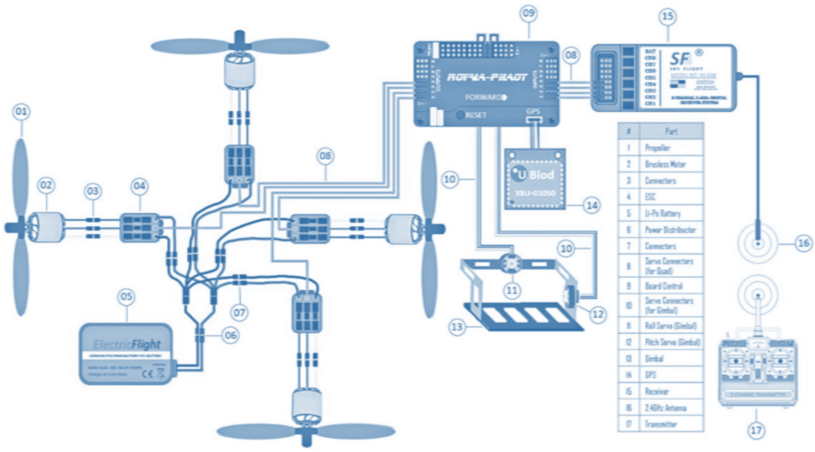

FIG. 9 Flight Controller and Global Positioning System implementation

Detect and avoid obstacles is the role of this block. The Collision Avoidance System (CAS) is equipped with some sensors or cameras catching in real time some information like shapes and their position in the space (Table 8). The analysis of the environment of the Quadcopter allows the collision avoidance system to determine if there is a risk of collision or not. Based on algorithms, the CAS can compute a new trajectory for the Quadcopter avoiding in security the obstacle.

This block can change according to the use of the Quadcopter. The principle is to use dismountable devices. Therefore, this block performs different functions related to the employed devices as illuminate, communicate or filming.

With the aim of simulating the way the UAVs work around the city, Matlab environment, and more specifically, the driving scenario tool were used.

Fig. 10 shows the trajectory followed by the drone through the streets of the chosen area of the city.

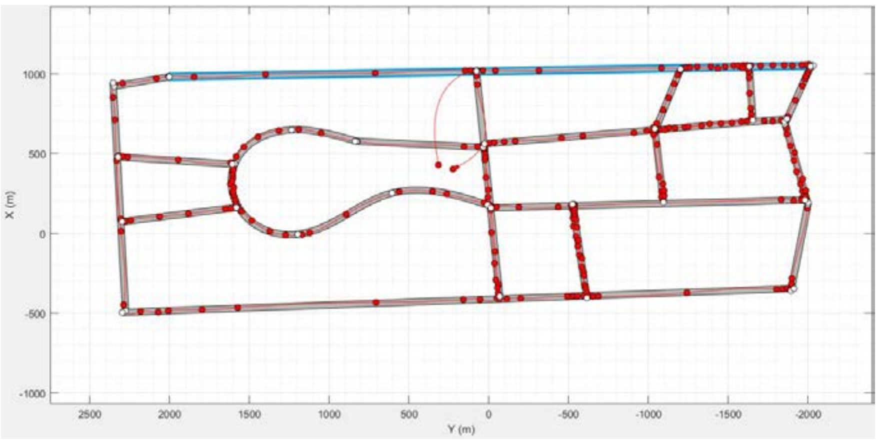

FIG. 10 Build trajectory simulation in MATLAB, based on Google Earth 2020 extraction of the streets layer of the district *Drumul Taberei* of Bucharest.

As explained in the previous paragraphs, one of the purposes of the system is to detect if there is a group of people larger than 3 or not. Figure 11 shows an example of a non-alert situation in comparison with an alert one. It detects the persons but since the condition was a group of at least person, the patrol would continue as normal.

FIG. 11 Non-alert detection vs. alert detection

4. CONCLUSIONS

The main goal of the EPS project was to study the possibility of using drones as part of the COVID-19 lockdown monitoring system. Quadcopters were studied for monitoring crowd and enforcing safety requirement.

Actual city surveillance systems were studied. Possibilities of using quadcopter for achieving city surveillance were depicted and legal aspect were highlighted. Afterward, computer vision and its application on UAV's for people counting were presented. Experimentation with people recognition using YOLO algorithm proved the ease of employing it. Studying the portfolio of available quadcopters on the market and making a requirement table lead to choosing the best UAV to monitor people in the street. Subsequently, an application case of city surveillance was made in Drumul Tabarei, Bucharest, Romania. Deployment of the monitoring system has been studied. A MATLAB simulation of an UAV evolving in Drumul Tabarei area and simulating people counting and detection allowed to experiment on the system.

Autonomous fleet of quadcopter equipped with HD cameras are a good mean for monitoring citizens in the street and showed promising results in terms of accuracy, reliability and safety. However, this system has to deal with strict legal aspects that evolve fast due to the recent development of quadcopters. Moreover, UAVs usage for population monitoring confronts people's privacy and citizen could show objection to the system and cause its destruction. Laws have to evolve at European model to ensure the development of city monitoring systems using quadcopters.

ACKNOWLEDGEMENTS

This paper represents an improved and extended version of the paper presented at the International Conference of Aerospace Sciences "AEROSPATIAL 2020", Bucharest, 15 - 16 October 2020, (Virtual Conference), Section 2 – Flight Mechanics, Paper S2.3.

This research was developed within the research partnership between [4]"POLITEHNICA" University of Bucharest, Faculty of Mechanical Engineering and Mechatronics and INCAS - National Institute for Aerospace Research "Elie Carafoli", through the EPS – European Project Semester programme.

The team of Science Advisors and Coordinators: Irina-Carmen ANDREI, Gina Florica STOICA, Nicoleta CRIŞAN, Delia PRISECARU, Cristian STOICA, Anca GRECULESCU.

The team of Tutors: Irina-Carmen ANDREI (INCAS Tutor), Nicoleta CRIŞAN (UPB Tutor).

We would also like to show our gratitude to Dr. Dragos-Daniel Ion-Guță, Head of Systems Division, and to all the research team members from INCAS, for supporting the EPS students groups and for providing expertise that greatly assisted the project research.

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