UAV Velocity Prediction Using Audio data

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***Abstract*—The Federal Aviation Administration (FAA) set the UAVs' speed limit to 100 mph. In this paper, we focused on detecting when the Unmanned Aerial Vehicle (UAV) exceeds a certain speed limit, then using that dataset to predict the velocity of a UAV. It is hard to detect a malicious UAV, but we can assume that a UAV over 100 mph is most likely malicious. An indoor environment will be used as a controlled environment and the dataset is divided into two classes: slow (0-9mph) and fast (10 mph). Support Vector Machine (SVM), Random forest, and Light Gradient Boosting (LGBM) were the machine learning model used for this research, and Convolutional Neural Network (CNN) was the deep learning model used for this research. The result shows that the CNN model has the highest accuracy for detecting when the UAV exceeds the slow velocity. This means the result shows the possibility of predicting the UAV velocity and also, can minimize the damage from these malicious UAVs. There are some limitations to this research. One limitation is the sound of the rotor of a UAV can emit a similar sound depending on the altitude and speed. A UAV flying at a slow speed at a high altitude can sound similar to a UAV flying at a high speed at low altitude.**

***Index Terms*—UAV, Velocity Prediction, Audio data, Machine Learning, Deep Learning**

I. Introduction

The use of Unmanned Aerial Vehicle (UAV) has increased around the world in many industries such as the police [1], medical, and agricultural fields. EMERGEN Research shows that the UAV industry in the US reached 23.6 billion (in USD) in 2021, and CONSORTIQ and Goldman Sachs forecast that the UAV industry in the US will grow from 90 to 100 billion in 2030 [2], [3]. India's medical industries utilize these UAVs in certain remote regions with the intent of delivering many kinds of packages such as blood, medical supplies, or food [4]. Yamaha RMAX, the first UAV approved by the Federal Aviation Administration (FAA), carried more than 55 pounds of fertilizers and pesticides to spray crops [5]. Even though these UAVs have good intentions, they can be abused by bad actors for malicious purposes. For example, a UAV crashed into one of the electrical grids in Pennsylvania in July 2020 as stated by the Federal Bureau of Investigation (FBI) which is an example of a UAV kamikaze attack [6]. To minimize the damage, the FAA limits UAV velocity to under 100mph [7]. If some UAVs fly over 100mph, it will be considered an illegal or malicious UAV.

Many research has been published to detect malicious UAVs using various datasets. For example, Yang et al. have experimented to detect UAVs with sound signals [8]. Another example is Knoedler et al. experimented with detecting and tracking a small UAV using passive Radar [9]. However, there is little research to predict the UAV velocity. The test was conducted by utilizing a microphone and recording these UAVs at different speeds. The reason is that there is little research about using a microphone to detect a UAV compared to other research using RADAR, LiDAR, and cameras.

This paper aims to detect if a UAV exceeds velocity boundary using UAV driving sound. The Mel Frequency Cepstral Coefficients (MFCCs) have been used to feature extraction from the sound dataset. Machine learning (ML) and deep learning models are compared to classify accuracy. To conduct the experiments, TN used Support Vector Machine (SVM), Random forest, and Light Gradient Boosting (LGBM) as a ML model for this research, and Convolutional Neural Network (CNN) was the deep learning model used for this research, either.

II. Literature Review

A. UAV Research Using Audio Data

UAV detection research has become active due to the potential malicious threats of these UAVs. To solve these threats of UAVs, research has also been conducted to detect UAVs using computer vision, RADAR, and audio data [10], [11]. Research using audio data shows promising results.

One research "A Feature Engineering Focused System for Acoustic UAV Detection" by Y. Wang, F. E. Fagian, K. E. Ho and E. T. Matson used multiple feature extraction methods (mfcc, mel, contrast, chroma, and tonnetz) to try and find the best feature extraction method to use when extracting UAV characteristics from audio data. SVM, Gaussian Naive Bayes (GNN), K-Nearest Neighbor (KNN), and Neural Network were used to find the best feature extraction. 300 audio data was collected from a DJI Phantom 4 and an Evo 2 Pro, and 600 more dataset will be collected from an outdoor environment.

The mfcc shows over 99% accuracy compared to other models (SVM: 99.6%, GNB: 99.5%, KNN: 99.0%, NN: 99.7%). A combination of machine learning and feature extraction shows an accuracy over 100% [8].

Audio data is a cost-effective way to distinguish UAVs despite having noise limitations. "Audio Based Drone Detection and Identification using Deep Learning" by E. Kubera, A. Wieczorkowska, A Kuranc, T. Słowik focused on the malicious activities of drones and conducted a study to identify UAVs using audio data. According to the paper, the use of SVM is effective for drone detection, but requires optimization of hand-created functions. To remediate this, deep learning was used as a way to have feature extraction and optimization. Experiments were conducted using three deep learning models: CNN, Recurrent Neural Network (RNN), and Convolutional Recurrent Neural Network (CRNN). RNN shows the shortest time required (389.02 seconds) that is required to process this data, but it also showed the lowest accuracy (57.16%) among the three models. CRNN has both RNN and CNN features. It has a time of 605.67 seconds and an accuracy above 90%. CNN has the longest time to train (807.10 seconds), however it shows an accuracy above 90%. CNN has better accuracy than CRNN by 0.72% [10], [12], [13].

B. *Vehicle Velocity Prediction Using Audio Data*

There have been some trial researchers to predict the speed of the objects by using audio data not only to detect.

One research has been conducted to predict the car's speed and the gear's position using the audio data of the engine using Gradient Boosting (GB). The author confirmed the relationship between audio and the car's speed. The author uses 3 microphones to get the dataset in controlled condition. The two microphones are attached on the inside and outside of the windshield to induce wind noise. The other microphone is placed next to the engine. After normalizing the dataset, the dataset was went under feature using MFCC, zero crossing rate, and spectral centroid. The audio contains features of speed and gear state, and this audio went under feature extraction where the result will be used as input to GB. GB's accuracy increases when the speed interval is large and time frame is minimal. When only using GB accuracy is under 75%. The author uses a correlation matrix to optimize GB. As a result, GB shows over 90% accuracy in gear position and speed prediction [14].

"Discovering Speed Changes of Vehicles from Audio Data" by E. Kubera, A. Wieczorkowska, A Kuranc, T. Słowik used machine learning to find out the changes in the velocity of passing vehicles. The dataset was created by installing a microphone about five feet from the road and obtaining audio data from vehicles passing by the road. Acquired audio data were parameterized through different methods based on audio features and spectrogram data before putting the audio data through machine learning. There are five types of machine learning used: random forest, SVM with linear kernel (SVML), SVM with quadratic kernel (SVMQ), SVM with RBF kernel(SVMR), and multi-layer perceptron (MLP). The result shows random forest, SVML, SVMQ, SVMR, and MLP accuracy results as 90.5%, 85.4%, 87.1%, 90.9%, and 88.6% respectively. Models that have the highest accuracy were put into a classifier ensemble that consists of the best performing classifiers. The ensemble resulted in an accuracy of 94.7% [15].

III. METHODOLOGY

Before you begin to format your paper, first write and save the content as a separate text file. Complete all content and organizational editing before formatting. Please note sections III-A–III-E below for more information on proofreading, spelling and grammar.

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Number equations consecutively. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

$$a + b = \gamma \tag{1}$$

Be sure that the symbols in your equation have been defined before or immediately following the equation. Use "(1)", not "Eq. (1)" or "equation (1)", except at the beginning of a sentence: "Equation (1) is . . ."

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- The subscript for the permeability of vacuum μ_0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter "o".
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example, write the quantity "Magnetization", or "Magnetization, M", not just "M". If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write "Magnetization (A/m)" or "Magnetization {A[m(1)]}", not just "A/m". Do not label axes with a ratio of quantities and units. For example, write "Temperature (K)", not "Temperature/K".

ACKNOWLEDGMENT

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REFERENCES

Please number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in [3]—do not use "Ref. [3]" or "reference [3]" except at the beginning of a sentence: "Reference [3] was the first …"

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For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

REFERENCES

[1] N. Chen, "Drones are responding to 911 calls in this California city." CNN.com. https://www.cnn.com/2019/04/12/us/california-drones-emergency-response/index.html (accessed May. 17, 2022)

[2] EMERGEN Research, "unmanned aerial vehicle market." EMERGENRESEARCH.com. https://www.emergenresearch.com/industry-report/unmanned-aerial-vehicle-market (accessed May. 20, 2022).

[3] D. Daly, "Drone Industry Outlook For the United States: 2020-2030." CONSORTIQ.com. https://consortiq.com/uas-resources/drone-industry-outlook-us-2020-2030 (accessed May. 20, 2022).

[4] A. Clarance, "What a drone picking up blood samples tells about healthcare in India." BBC.com, https://www.bbc.com/news/world-asia-india-61267750 (accessed May. 15, 2022).

[5] A. Meola, "Precision agriculture in 2021: The future of farming is using drones and sensors for efficient mapping and spraying." INSIDER.com. https://www.businessinsider.com/agricultural-drones-precision-mapping-spraying (accessed May. 16, 2022).

[6] B. Crumley, "FBI says PA electricity station likely 'target' of drone incident." DroneDJ.com. https://dronedj.com/2021/11/04/fbi-says-pa-electricity-station-likely-target-of-drone-incident/ (accessed May. 15, 2022)

[7] Federal Aviation Administration. *Small Unmanned Aircraft Systems (UAS) Regulations (Part 107)*. [Online]. Available: FAA/newsroom/small-unmanned-aircraft-systems-uas-regulations-part-107

[8] Y. Wang, F. E. Fagian, K. E. Ho, and E. T. Matson, "A Feature Engineering Focused System for Acoustic UAV Detection," *2021 5th IEEE Int. Conf. on Robot. Comput. (IRC)*, 2021, pp. 125-130, doi: 10.1109/IRC52146.2021.00031.

[9] B. Knoedler, C. Steffes, and W. Koch, "Detecting and Tracking a Small UAV in GSM Passive Radar Using Track-before-Detect," *2020 IEEE Radar Conf. (RadarConf20)*, 2020, pp. 1-6, doi: 10.1109/RadarConf2043947.2020.9266673.

[10] S. Al-Emadi, A. Al-Ali, A. Mohammad, and A. Al-Ali, "Audio Based Drone Detection and Identification using Deep Learning," *2019 15th Int. Wireless Commun. & Mobile Comput Conf. (IWCMC)*, 2019, pp. 459-464, doi: 10.1109/IWCMC.2019.8766732.

[11] S.Jamil, Fawad, M.Rahman, A.Ullah, S.Badnava, M.Forsat, and S.S.Mirjavadi, "Malicious UAV Detection Using Integrated Audio and Visual Features for Public Safety Applications", *Sensors (Basel) vol. 20,14 3923. , 2020*, doi: 10.3390/s20143923.

[12] S. Seo, S. Yeo, H. Han, Y. Ko, K. E. Ho, and E. T. Matson, "Single Node Detection on Direction of Approach," *2020 IEEE Int. Instrum. and Meas. Technol. Conf. (I2MTC)*, 2020, pp. 1-6, doi: 10.1109/I2MTC43012.2020.9129016.

[13] S. Li, H. Kim, S. Lee, J. C. Gallagher, D. Kim, S. Park, and E. T. Matson, "Convolutional Neural Networks for Analyzing Unmanned Aerial Vehicles Sound," *2018 18th Int. Conf. on Control, Automat. and Syst. (ICCAS)*, 2018, pp. 862-866.

[14] H. V. Koops, and F. Franchetti, "An ensemble technique for estimating vehicle speed and gear position from acoustic data," *2015 IEEE Int. Conf. on Digit. Signal Process. (DSP)*, 2015, pp. 422-426, doi: 10.1109/ICDSP.2015.7251906.

[15] E. Kubera, A. Wieczorkowska, A Kuranc, and T. Słowik "Discovering Speed Changes of Vehicles from Audio Data." *Sensors (Basel, Switzerland) vol. 19,14 3067.*, 2019, doi:10.3390/s19143067

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