Machine Learning based Real Time UAV Detection using Smartphone

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MIDTERM PRESENTETION

Team Introduction, Project goal & Motivation

Team Introduction

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Introduction

Acronyms

- **ML : M**achine **L**earning
- **CNN : C**onvolutional **N**eural **N**etworks
- **RF : R**adio **F**requency
- **YOLO : Y**ou **O**nly **L**ook **O**nce
- **MFCC : M**el **F**requency **C**epstral **C**oefficient
- **NN : N**eural **N**etwork
- **GNB : G**aussian **N**aïve **B**ayes algorithm
- **KNN : K N**earest **N**eighbor algorithm
- **SVM : S**upport **V**ector **M**achine algorithm
- **ReLU : Re**ctified **L**inear **U**nit
- **TCP: T**ransfer **C**ontrol **P**rotocol
- **UAV : U**nmanned **A**erial **V**ehicles
- **CAGR : C**ompound **A**nnual **G**rowth **R**ate

Introduction

Project Motivation

- Use of drones [1]
  - Military drones
  - Drones for delivery
  - Drones for emergency rescue
  - Drones in medicine
  - Drones for photography

- Global unmanned aerial vehicle (UAV) market was valued at US$ 56.7 Billion in 2021 and is estimated to reach a valuation of US$ 106.03 Billion by 2030 at a CAGR of 7.5% from 2022 to 2030 [2].

[1] Drones. BuiltIn. (n.d.). Retrieved January 30, 2023, from https://builtin.com/drones.
[2] B. Aamir, "Unmanned Aerial Vehicle (UAV) market to reach US$ 106.03 billion by 2030 - astute analytica," GlobeNewswire News Room, 17-Nov-2022. [Online]. Available: https://www.globenewswire.com/en/news-release/2022/11/17/2558200/0/en/Unmanned-Aerial-Vehicle-UAV-Market-to-Reach-US-106-03-Billion-by-2030-Astute-Analytica.

Introduction

Project Motivation

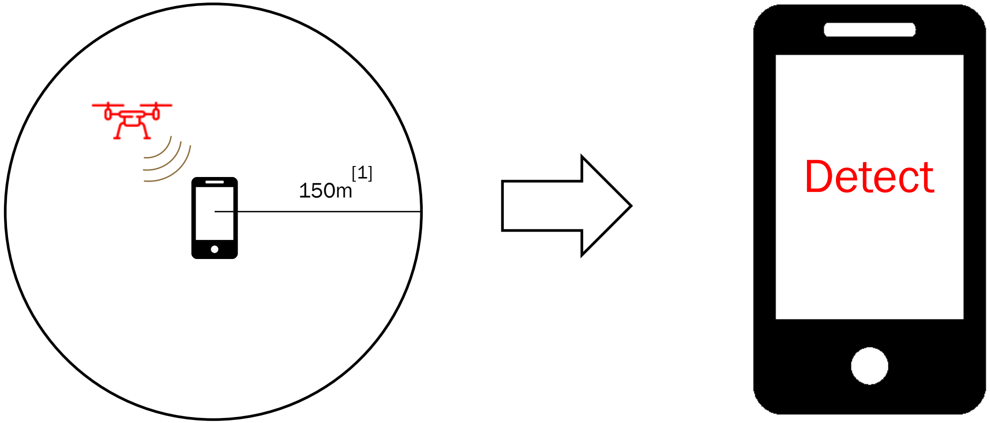
- **As drone technology advances, incidents of careless misuse, military surveillance, and malicious activity of drones have increased[1].**
- **Drone assassination attempt on Venezuelan President Nicolas Maduro in 2018[2].**
- **Three people were arrested for carrying cigarettes and phones by drone to a prisoner in 2020[3].**
- **Drones also allow criminals to plot a heist, hack into your phone or laptop[4].**

⇒ Drone detection ability is important to prevent accidents, crimes caused.

[1] R. Schradin, "Malicious drones - the UAV threat facing law enforcement and military," The Last Mile, 08-Sep-2022. [Online]. Available: https://thelastmile.gotennapro.com/malicious-drones-the-uav-threat-facing-law-enforcement-and-military/. [Accessed: 29-Jan-2023].
[2] BBC. (2018, August 5). *Venezuela president Maduro survives 'drone assassination attempt'*. BBC News. Retrieved January 30, 2023, from https://www.bbc.com/news/world-latin-america-45073385
[3]"Report: Trio planned to use drone to to get tobacco, phones to Inmate," *Northwest Georgia News*, 13-Apr-2020. [Online]. Available: https://www.northwestgeorgianews.com/report-trio-planned-to-use-drone-to-to-get-tobacco-phones-to-inmate/article_44c25a12-7d96-11ea-8c97-73fe94e065d4.html. [Accessed: 30-Jan-2023].
[4] R. Tabbara, "15 reasons to install a drone detection system at your company's infrastructure," 911 Security. [Online]. Available: https://www.911security.com/blog/15-reasons-to-install-a-drone-detection-system-at-your-companys-infrastructure. [Accessed: 29-Jan-2023].

Project Goal

- **Real Time UAV Detection with Smartphone**



[1] B. Taha and A. Shoufan, "Machine Learning-Based Drone Detection and Classification: State-of-the-Art in Research," in IEEE Access, vol. 7, pp. 138669-138682, 2019, doi: 10.1109/ACCESS.2019.2942944.

RELATED WORKS

Real-time UAV Detection using Smartphones

Implementation of UAV detection using smartphone

RELATED WORKS

Relevant literature for detecting Unmanned Aerial Systems

- **Vision based** UAV detection - B.-G. Han el al[1]. YOLO algorithm employs convolutional neural networks (CNN) to detect objects in real-time. This solution requires huge labeled datasets and have problem with visual data's noise.

- **Radar based** - B Torvik et al. [2] proposed 100% accuracy results by simple nearest neighbor approach for binary classification between UAVs and birds. However, this method has Radar Cross-Section and range limitation[3].

- **Radio frequency**-based UAV detection use RF signals from controller and achieved 80~95% accuracy with ML learning techniques. However, this solution fails when the drone is operated in autonomous mode[2].

[1] B. –G. Han et al. "Eesign of a Scalable and Fast YOLO for Edge –Computing Devices", Sensors, Bvol. 20, no. 23, 2020.
[2] B. Torvik, K. E. Olsen and H. Griffiths, "Classification of birds and uavs based on radar polarimetry", *IEEE geoscience and remote sensing letters* , vol. 13, no. 9, pp. 1305-1309, 2016.
[3] B. Taha and A. Shoufan, "Machine learning-based drone detection and classification: State-of-the-art in research", *IEEE Access*, vol. 7, pp. 138669-138682, 2019.

RELATED WORKS

Acoustic node for detecting Unmanned Aerial Systems

- The rotation of the drone's **rotor blades produces a humming sound** that can be sensed and recorded, even within the range of human hearing.

- Y Wang *et al.*[1] Machine learning Algorithm and **MFCC** feature were applied to detect UAV detection.

- **Using features for classification** provide explanations for understanding how the ML classification was produced.

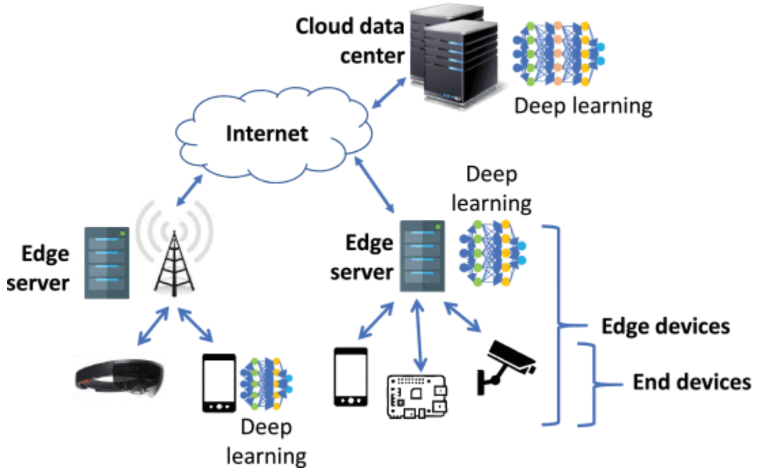
- This solution provided 78% accuracy and fewer computational resources than others.

[1] Y. Wang et al. "A Feature Engineering Focused System for Acoustic UAV Detection", 2021 Fifth IEEE International Conference on Robotic Computing (IRC), 2022.

RELATED WORKS

Acoustic UAV detection on Edge device

- 3 Challenge : Latency, Scalability, Privacy [1]
- TensorFlow lite was proposed for mobile and embedded devices, with mobile GPU support.
- In contrast to cloud computing, Edge computing's latency is significantly less, as numerous of data does not have to travel through a backhaul network to cloud[2].



[Deep learning on edge devices and cloud data centers]

[1, Fig 1] J. Chen and X. Ran, "Deep learning with edge computing: A review", Proc. IEEE, vol. 107, no. 8, pp. 1655-1674, Jul. 2019.
[2] P. Joshi et al. "Enabling All In-Edge Deep Learning: A Literature Review" 2023, IEEE Access (Volume: 11)

Methodology

Real-time UAV Detection using Smartphones

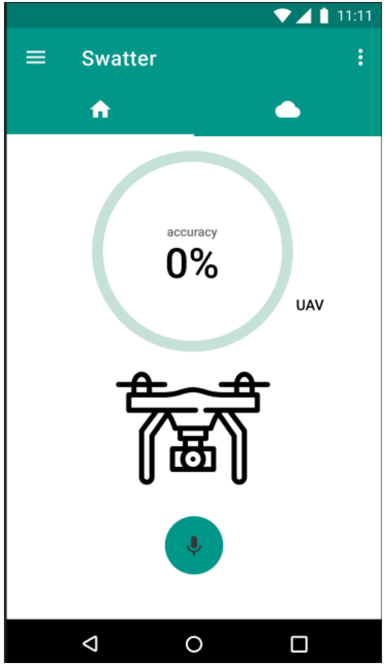
User Flow, System Flow Chart,
Machine Learning Algorithm

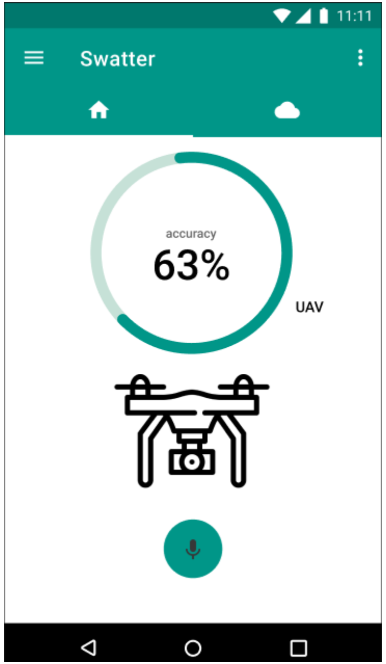
Methodology

User Flow

1. Open the app and record sound.

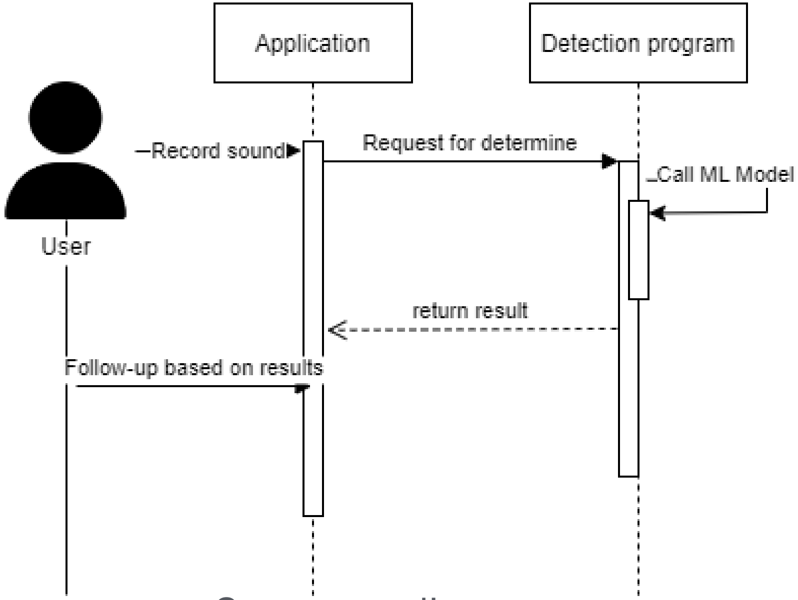
2. Wait and check a result



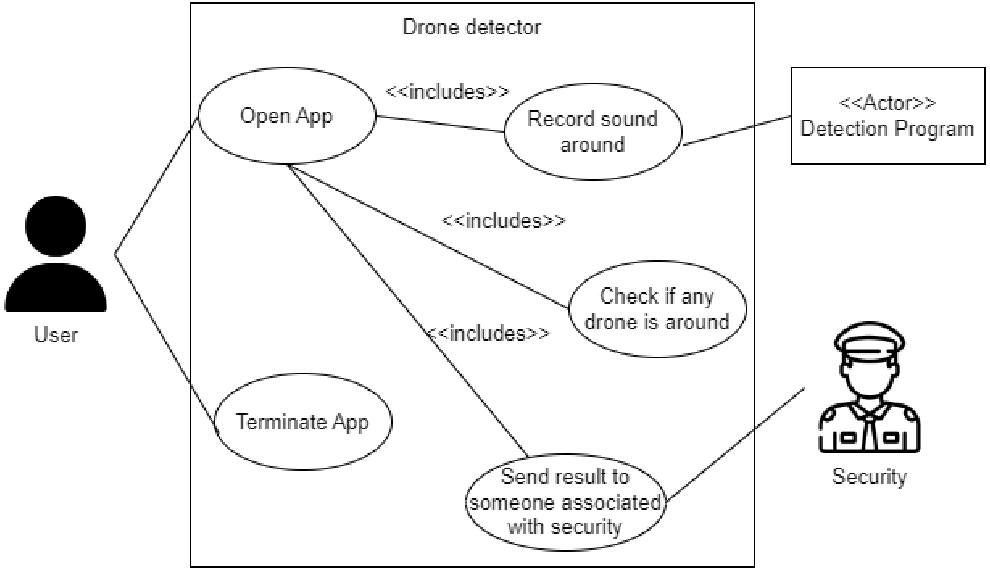


Methodology

Sequence diagram, Use Case diagram



Sequence diagram

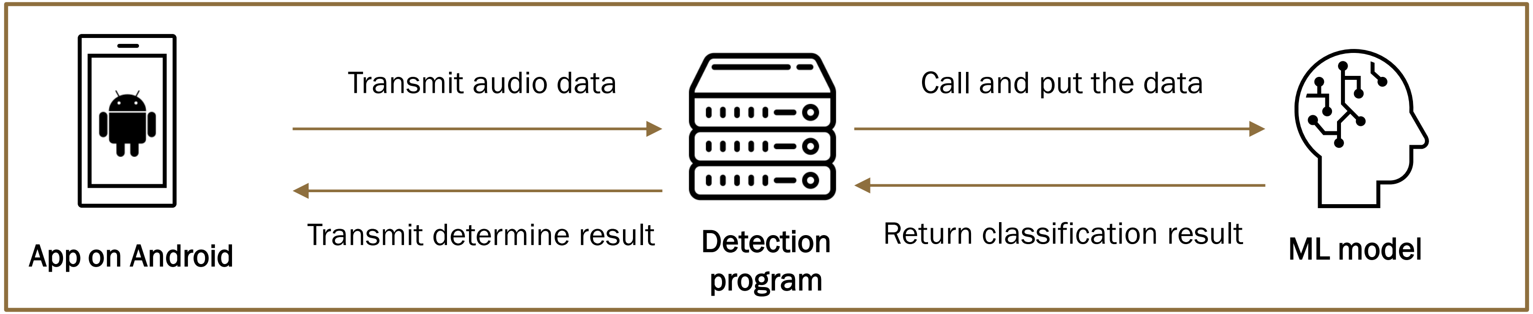


Use Case diagram

Polytechnic Institute

Methodology

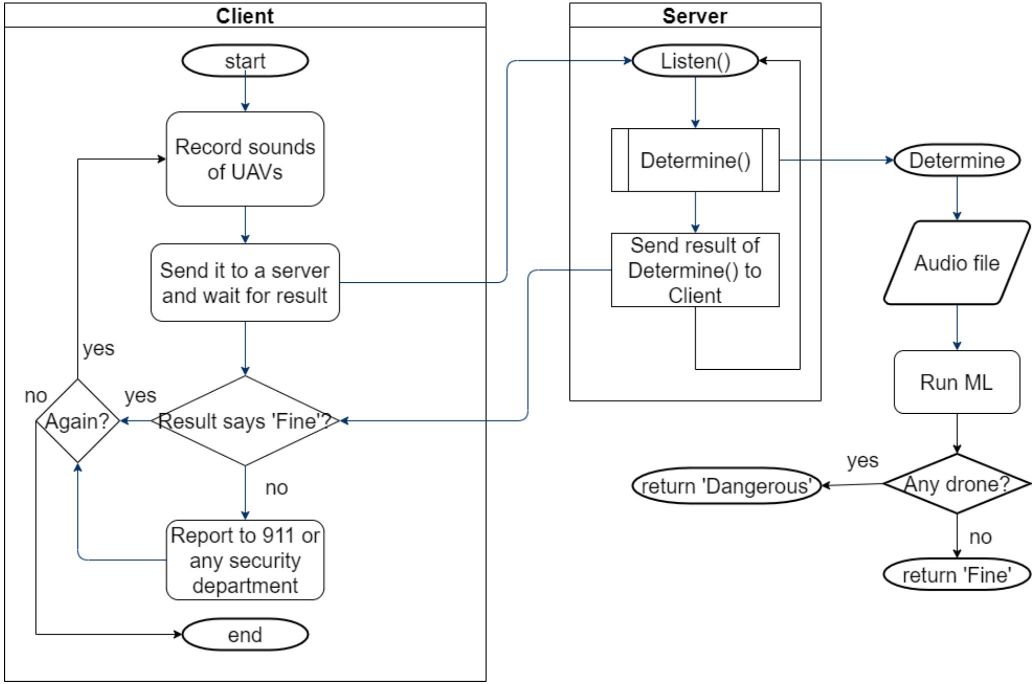
System Flow



1. **Transmit audio data to detection program.**
2. **Run Machine Learning model and put received data.**
3. **Binary Classification with input data.**
4. **Detection program transmit classification result to the app.**

Methodology

System Flow Chart



Methodology

System Requirements

Android device (version 11.0~)

Azure

Cloud Server

TensorFlow

Machine Learning

1. **Android Device to use the app**
2. **A Cloud server for transmitting and saving ML model**
3. **TensorFlow for running Machine Learning model**
4. **Trained Machine Learning model for classification.**

Progress

Real-time UAV Detection using Smartphones

Each member's current progress

Progress

Selecting Features of Audio data

- Efficient to train ML models than raw data
- In another research[1], researchers select 5 features that have more than 2 shapes.
- Librosa library is fit for extracting features.

Name of features	Num of Shape
mfcc	40
mel	128
contrast	7
chroma_stft	12
tonnetz	6

[1] Y. Wang et al, "A Feature Engineering Focused System for Acoustic UAV Detection," *2021 Fifth IEEE International Conference on Robotic Computing (IRC)*, Taichung, Taiwan, 2021, pp. 125-130

Progress

Verifying Feature Extraction

- Feature extraction using sample data
  - Librosa built-in data are used
- Verified that shapes are matched with previous paper[1]

```python
## Verify shape of features
df = pd.DataFrame(index = ['MFCC','mel','chroma_stft','contrast','tonnetz']
                  ,columns = ['Shape'])
#df.index.name = 'Features'

## sample data
y, sr = librosa.load(librosa.ex('trumpet'))
print(y)

## MFCC
mfcc = librosa.feature.mfcc(y, sr=sr)
mfcc = np.mean(mfcc.T,axis=0)
# print(mfcc)
df.iloc[0] = mfcc.shape[0]

## mel
mel = librosa.feature.melspectrogram(y,sr=sr)
mel = np.mean(mel.T, axis=0)
df.iloc[1] = mel.shape[0]

## chroma_stft
chroma_stft = librosa.feature.chroma_stft(y,sr)
chroma_stft = np.mean(chroma_stft.T, axis=0)
df.iloc[2] = chroma_stft.shape[0]

## contrast
stft = np.abs(librosa.stft(y))
contrast = librosa.feature.spectral_contrast(S=stft,sr=sr)
contrast = np.mean(contrast.T, axis=0)
df.iloc[3] = contrast.shape[0]

## tonnetz
tonnetz = librosa.feature.tonnetz(y=librosa.effects.harmonic(y),sr=sr)
tonnetz = np.mean(tonnetz.T, axis=0)
df.iloc[4] = tonnetz.shape[0]

print(df)
```

[Program for verifying feature extraction]

	Shape
MFCC	40
mel	128
chroma_stft	12
contrast	7
tonnetz	6

[Results of program]

[1] Y. Wang et al, "A Feature Engineering Focused System for Acoustic UAV Detection," *2021 Fifth IEEE International Conference on Robotic Computing (IRC)*, Taichung, Taiwan, 2021, pp. 125-130

Progress

Selecting Algorithm

- Machine Learning is our main method for UAV detection.
- Using ML algorithms suitable for audio classification.
- In another paper[1], 4 algorithms were selected.

Name of Algorithm	Hyperparameters
NN (Neural Network)	Learning rate = 0.001, epochs = 30
GNB (Gaussian Naïve Bayes)	Default
KNN (K-Nearest Neighbor)	N_neighbors = 6, others are default
SVM (Support Vector Machine)	C = 6, kernel as linear

[1] Y. Wang et al, "A Feature Engineering Focused System for Acoustic UAV Detection," *2021 Fifth IEEE International Conference on Robotic Computing (IRC)*, Taichung, Taiwan, 2021, pp. 125-130

Progress

Structure of Neural network model

- Neural network model structure
- High flexibility, depends on developer
- 3 Dense layers
  - 128 nodes for 2 layers, 1 node for output
- 2 Activation layers
  - 'ReLU' function
- 2 Dropout layers
  - Dropout rate : 0.1

```
Layer (type)                 Output Shape              Param #
=================================================================
input_2 (InputLayer)         [(None, 128)]             0

dense_3 (Dense)              (None, 128)               16512

activation_2 (Activation)    (None, 128)               0

dropout_2 (Dropout)          (None, 128)               0

dense_4 (Dense)              (None, 128)               16512

activation_3 (Activation)    (None, 128)               0

dropout_3 (Dropout)          (None, 128)               0

dense_5 (Dense)              (None, 1)                 129

=================================================================
Total params: 33,153
Trainable params: 33,153
Non-trainable params: 0
```

[Structure for NN model]

Progress

Code for model training

- scikit-learn library is used (v 1.0.2)

  - SVM, GNB, KNN models

- 'TensorFlow' library is used (v 2.10.0)

  - NN model

```
# Modeling
## SVM(Support Vector Machine)
def svm_base(X,y,C,kernel='linear'):
    svm_model = svm.SVC(C, kernel=kernel)
    return svm_model

## GNB (Gaussian Naive Bayes)
def gnb_base(X,y):
    gnb_model = naive_bayes.GaussianNB()
    return gnb_model

## KNN (K-Nearest-Neighbor)
def knn_base(X,y, n_neighbors=6):
    knn_model = neighbors.KNeighborsClassifier(n_neighbors=n_neighbors)
    return knn_model

## NN(Nueral Network)
def neural_base(shape):
    input_tensor = Input(shape=(shape))
    x = Dense(128)(input_tensor)
    x = Activation('relu')(x)
    x = Dropout(rate=0.1)(x)
    x = Dense(128)(x)
    x = Activation('relu')(x)
    x = Dropout(rate=0.1)(x)

    output = Dense(1, activation='sigmoid')(x)

    model = Model(inputs=input_tensor, outputs=output)
    model.summary()
    return model
```

[Program for model training]

Progress

Server program

```
[joonki@localhost ~]$ telnet 192.168.227.131 7367
Trying 192.168.227.131...
Connected to 192.168.227.131.
Escape character is '^]'.
HI!
This is Joonki Rhee!
I'm testing server on Linux!
Connection closed by foreign host.
```

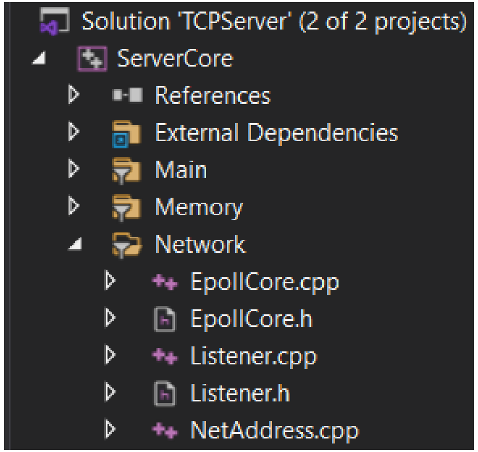
[Client]

```
Hello from SWATTER Server Socket Test!
Before While
In While, event count[1]
User Accept
In While, event count[1]
Recv Data from [7]
Client[7]: HI!

In While, event count[1]
Recv Data from [7]
Client[7]: This is Joonki Rhee!

In While, event count[1]
Recv Data from [7]
Client[7]: I'm testing server on Linux!
```

[Server]



[Classes of Server program]

- TCP/IP Server for data transmitting
- Able to withstand high network load
- Call ML model to classify
- Will be executed on Linux

Future work

Real-time UAV Detection using Smartphones

Project’s next steps

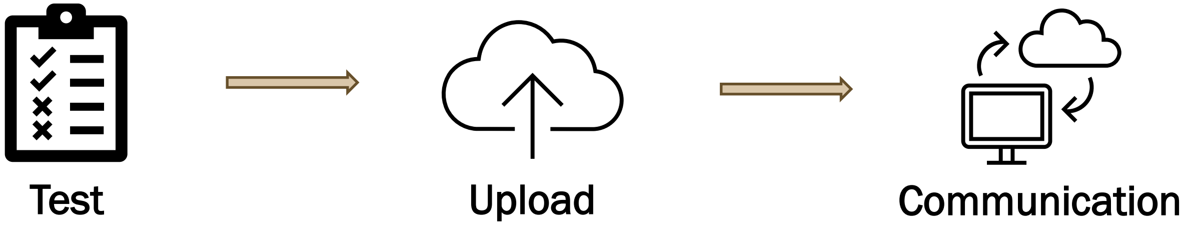
Future Work

Training models with UAV audio data

- Finalize skeleton code for the program.
- Train the models with UAV sound data and save the models.
- Extract features of UAV sound data and run the models.

Future Work

Completing Cloud Server development

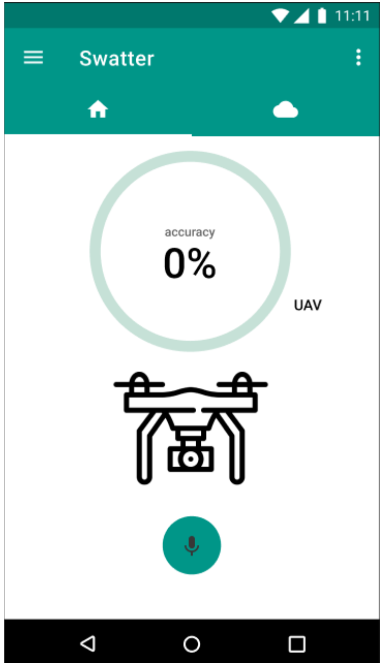


- Designing packets for communication
- Testing the communication and performance
- Uploading to cloud and executing it
- Balancing network load for smooth service

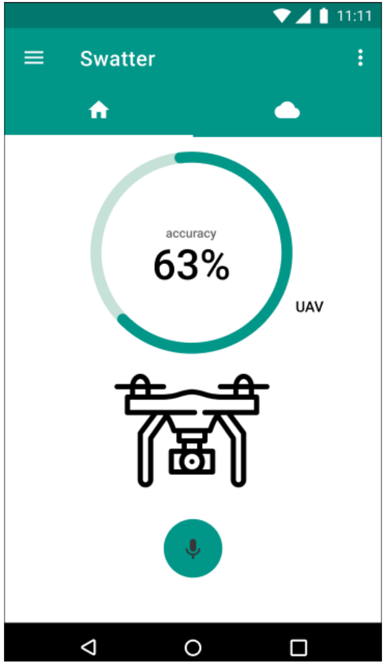
Future Work

Developing Application for User

- Convert model using TensorFlow lite
- Requirement of development
  – Kotlin (java), Android API 24
- Developing application – Three main Function
  - Record sound
  - Draw result of UAV Inference
  - Transmit sound data to cloud server



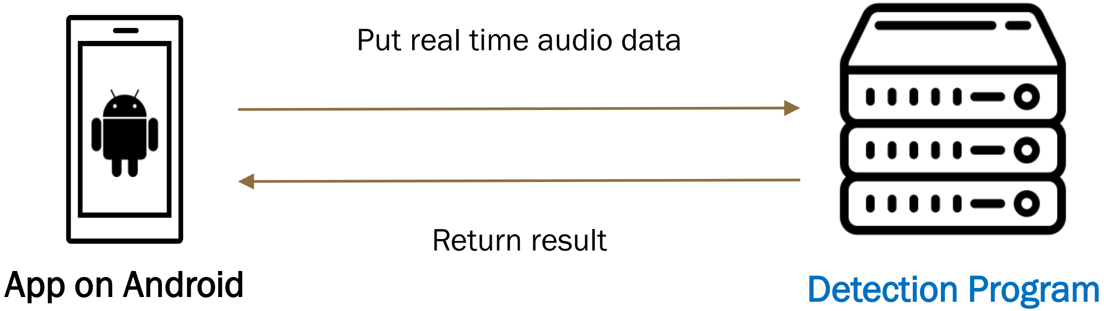
[Example UI before detection]



[Example UI after detection]

Future Work

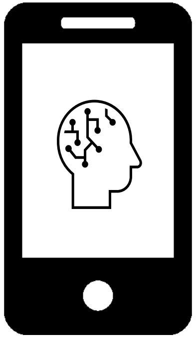
Using Machine Learning on Smartphones



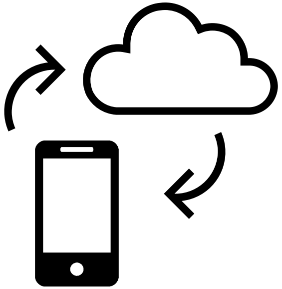
- Implement ML model for UAV detection in real time.

  -> Figure out a method to transmit and process data in real time.

Adjusting Models



VS



Smartphones

Cloud Computing

- Test for comparing inference time and performance between two different method.
- Select better method for UAV detection.

Q&A

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Thank you!

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