Audio-based Drone Ranging and Localization using Deep Learning

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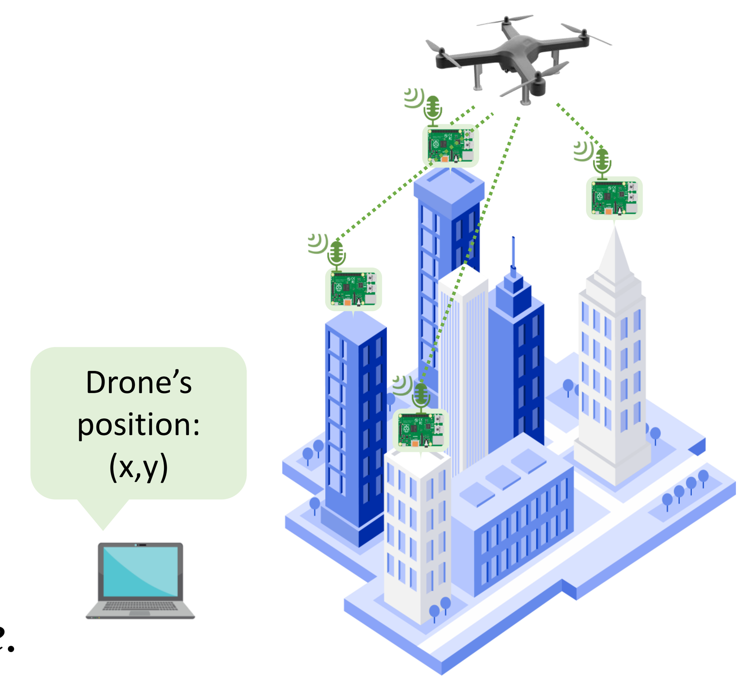
Introduction and Scenario

Introduction

- Accurate distance measurement and localization of drone became critical not only for its mission but also for detecting and identifying malicious usages.
- Although TOA-based acoustic ranging method, acoustic signature based localization, vision-based search, and deep learning based drone detection techniques exist, their usability and scope have yet been limited.
- We propose a *real-time* audio-based system that uses *deep learning* for not only detecting but also *ranging* and *localization* of a drone.

Scenario

- Our system consists of several embedded sensor nodes & a server.
- Each embedded sensor node
  - records audio sound → (pre-)processes it → sends the data to the server.
- The server
  - receives data from each node → computes the final location in *real-time.*



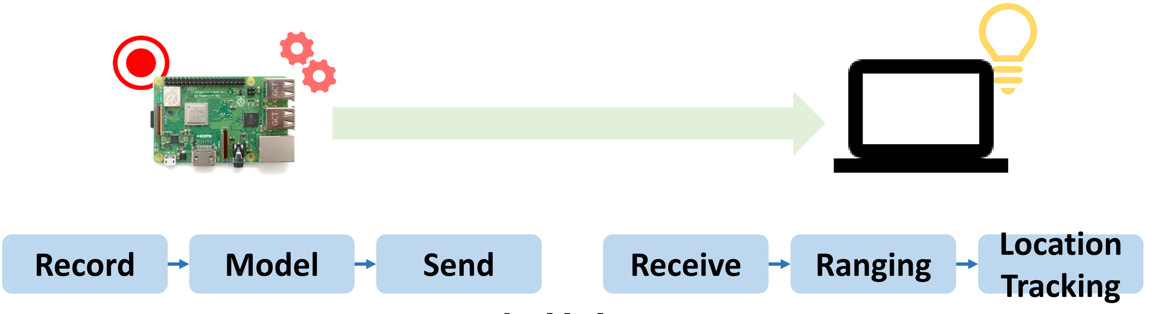
System Design

Approach

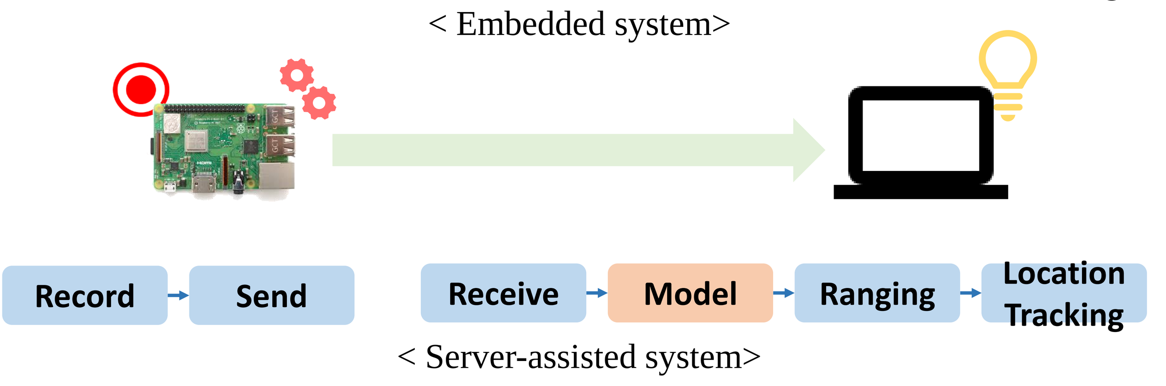
- We collected ~1100 seconds of drone and background sounds in various environments and pre-processed it via Mel-frequency Cepstral Coefficients.
- Deep learning models used: Convolutional Neural Network (CNN) and Deep Neural Network(DNN).
- The key idea is to use the classification probability output of audio-based deep learning for ranging.
- Localization via trilateralization using the ranges from multiple sensor nodes.

System Design

- Training results of deep learning model → CNN: 90.8% accuracy and DNN: 97.1%
- Based on the results and various aspects of our paper's purpose, we decided to focus on DNN.
- In order to design a system that can process in real-time, we first needed to investigate whether this is feasible through in–depth analysis of latency components of the system.
- For this purpose, we implemented two prototype systems as shown below:



< Embedded system>



< Server-assisted system>

System Comparison

- The total time required to process one second audio was only ~0.86 second for the server-assisted system, whereas embedded approach took ~6.23 second.
- Based on the result, we concluded that the server-assisted approach is suitable for real-time processing whereas the embedded approach is incapable.

Processing time	Embedded system	Server-assisted system
Recording	0.9299	0
Waiting	0	0.3
I/O	0.0649	0.007
MFCC	0.6346	0.0792
Layer	4.3553	0.2084
Model	0.8884	0.1226
Prediction	0.2807	0.1398
Send	0.0005	0
Total	6.2244	0.857

Ranging Algorithm

- Idea: Estimate distance based on deep learning classification result.
- Using the detection (classification) probability output of the audio-based deep learning algorithm as an input to a model that can estimate the distance to a drone.
- For this purpose, we have explored two kinds of classification method.
- The first method is binary classification.
  → calculate distance based on the accuracy of the presence or absence.
- The second method is multi-class classification.
  → train data according to the distance of the drone.
  → generate classification probability of each class for the test input.
  → calculate distance based on a weighted average of those classified distance and the classification probability.

Background (no drone)	Drone (within 10meters)
~1100 seconds	~1100 seconds

< Binary classification classes>

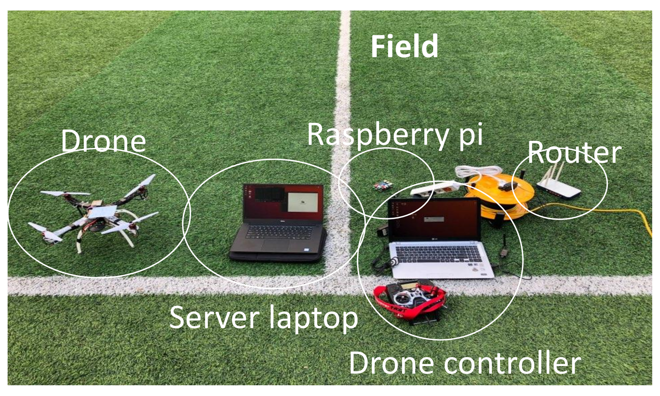
Background (no drone)	Drone (within 1meters)	Drone (about 10meters)	Drone (about 20meters)	Drone (about 50meters)
~1100 seconds	~300 seconds	~300 seconds	~300 seconds	~300 seconds

< Multi-class classification classes>

Preliminary Experiment Result

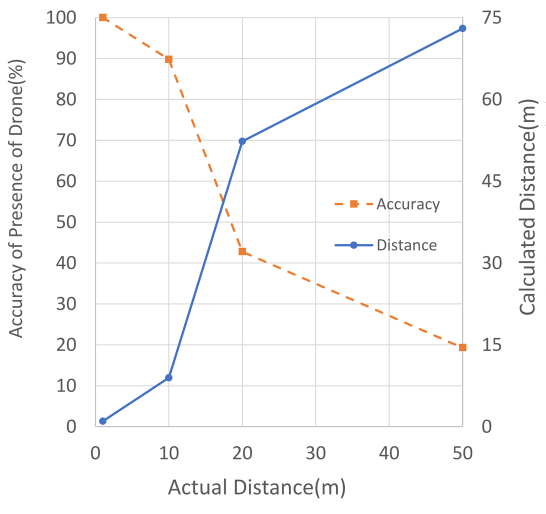
Experiment Environment

- We implemented a prototype of our system using Raspberry Pi 3 with an audio card as sensor node, and used a Linux laptop as the server.

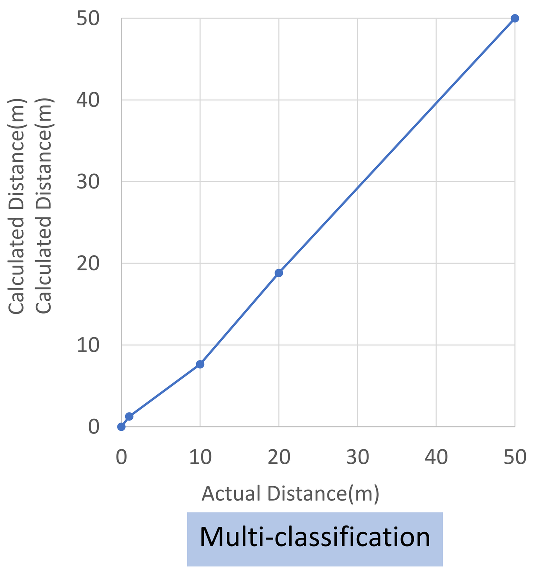


Result

- Drone detection accuracy output and calculated distance from DNN-based binary-classification and calculated distance from DNN-based multi-classification.



Binary-classification



Multi-classification

- Binary classification
  - the probability of drone presence is not linearly correlated with the distance.
- Multi-class classification
  - estimated distance is well matched within acceptable error range.
- Based on these results, our ranging and localization algorithm will be based on **multiclass classification** model.

Future work

- Further investigation on multi-class classification and enhancement.
- Devising an accurate model for range estimation based on classification result.
- Implementing a large-scale system that can be used in the real-world.