TRANSPORTATION LEARNING NETWORK

A partnership with MDT•NDDOT•SDDOT•WYDOT and the Mountain-Plains Consortium Universities

Welcome!

Automated Image-Based Aircraft Tracking

Presented by:

Mohammad Farhadmanesh

Our partners:

MOUNTAIN-PLAINS CONSORTIUM | MONTANA MDT DEPARTMENT OF TRANSPORTATION | NORTH DAKOTA Be Legendary. Transportation | SD DEPARTMENT OF TRANSPORTATION | WYOMING DEPARTMENT OF TRANSPORTATION | NDSU | UPPER GREAT PLAINS TRANSPORTATION INSTITUTE TRANSPORTATION LEARNING NETWORK

This material is subject to change at the discretion of the presenter. If there are changes, TLN will obtain a revised copy to be posted on the LMS for download after the presentation. Thank you.

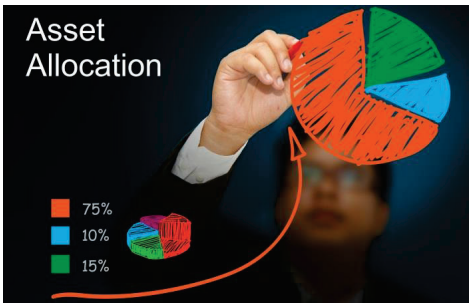
Contents

- Importance of the project (non-towered airports)
- Review of the existing methods
- Benefits of a vision-based method
- The developed camera-based method
  - Camera layouts
  - Machine vision
- Case studies (data collections)
- System performance
  - Counting, activity recognition, and identification accuracy
  - Limitations (OCR friendly, night time)
- Implementation (airports configurations)
  - Hardware and software and cost analysis
  - Spin-off benefit (automating of ST/C cameras)
- Future Research (prototyping and edge computing)

2

Non-Towered Airport Operations

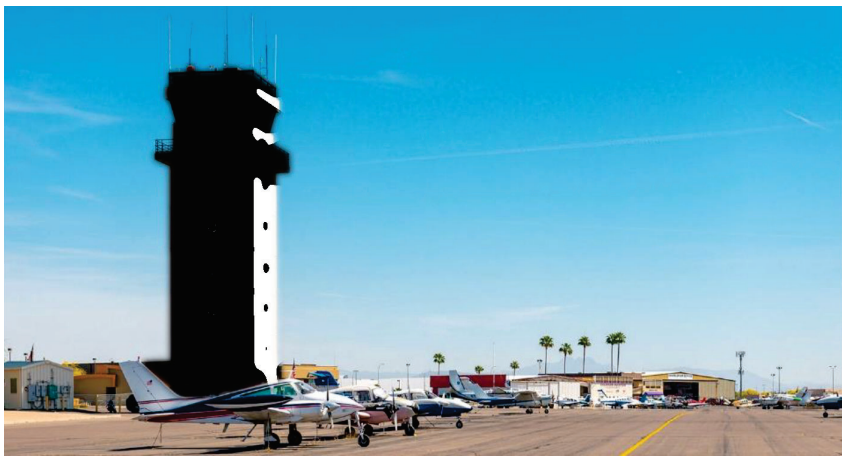
- Airport Operation Measurement Necessity
  - Fair allocation of federal and state level budgets
  - Accurate preparation of airport master plans
  - Facilitating environmental studies
  - Air traffic control tower justification
- Operation Identification Benefits
  - Security purposes (unauthorized landings)
  - Safety purposes (incursions)



3

Non-Towered Airport Operations

- Control Towers deliver operation measurement
- 97% of the U.S. airports are non-towered



4

Existing Methods

1. Acoustical counting method
2. ADS-B based counting
3. Radio click counting

5

Existing Methods

1. Acoustical counting method

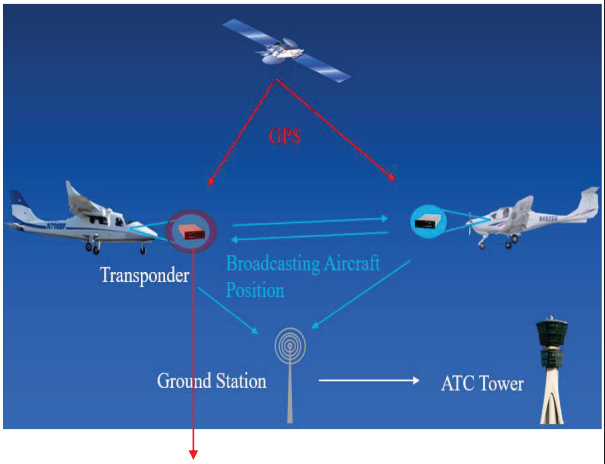
- Misses most landing operations
- Misses quieter aircraft
- Inaccurate counting
- No identification

6

Existing Methods

2. ADS-B based counting

- Low equipage rate of the current GA aviation fleet with transponders
- Mode C the prevalent mode (Requires an interrogator + No ID)
- Most non-towered airports are not inside the airspace where ADS-B enabled avionics will be required by FAA



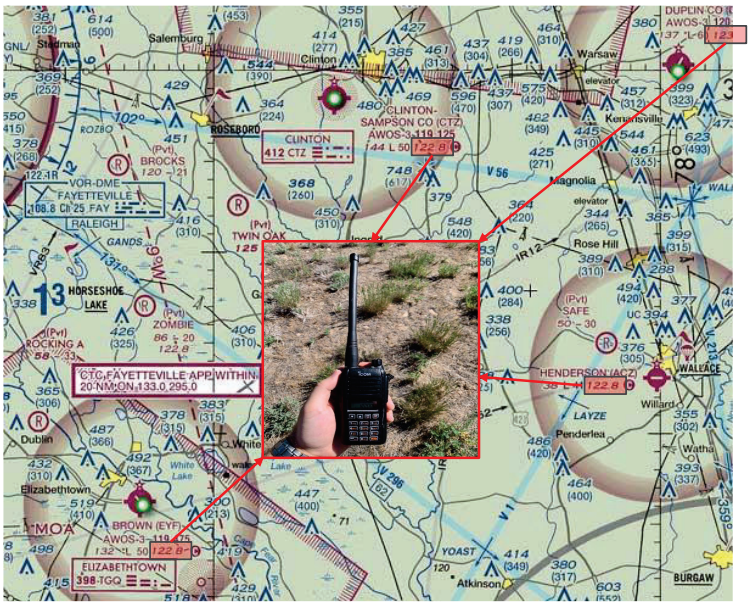
Transponder signal mode types:
Mode S Extended Squitter
Mode S Short Squitter
Mode C (no Hex ID)

7

Existing Methods

3. Radio click counting (GARD)

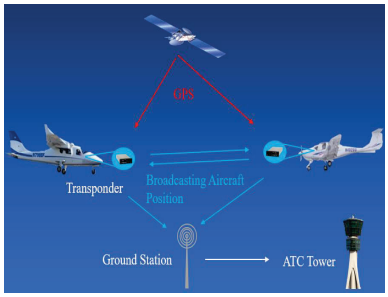
- Inaccurate counting
- Not for airport with shared Unicom frequency
- No identification



8

Benefits of a Vision-based Method

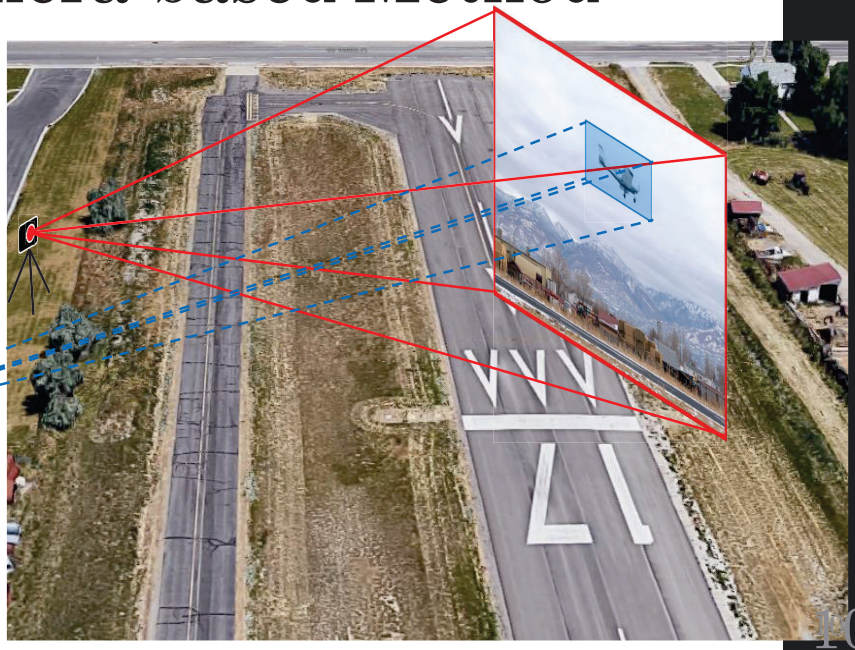
- Do not need cooperative aircraft
- Do not rely on radar or radio information
- Not sensitive to aircraft model (sound of engine, …)
- Has been used for automation of many tasks in the aviation systems



9

Developed Camera-based Method

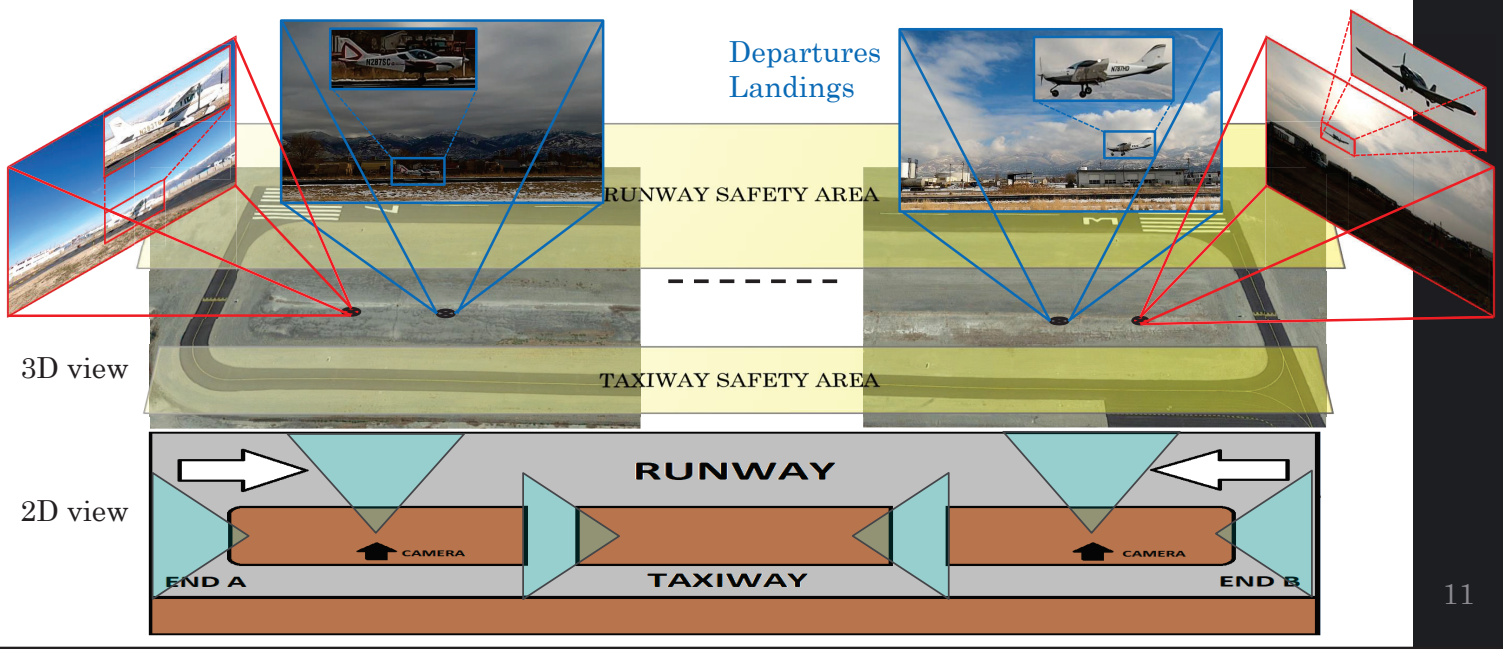
- Major elements:
  - Camera Layout
  - Machine Vision



10

Camera Layouts

Departures
Landings:
Arrivals
Touch&Goes



3D view

2D view

11

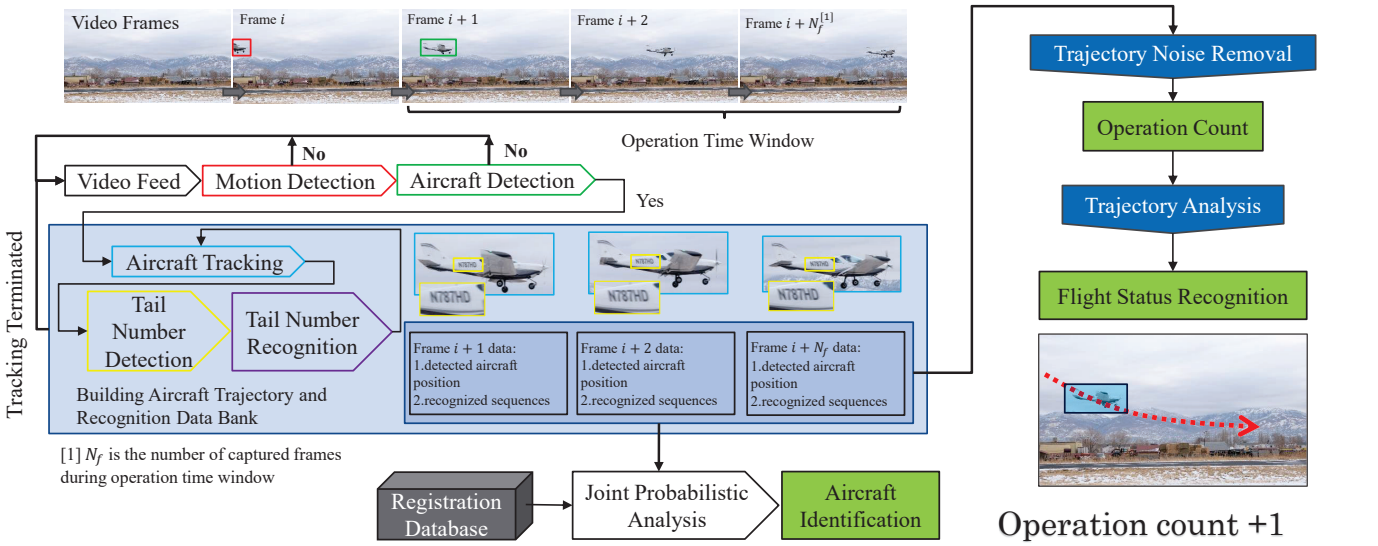
Machine Vision

- Software Modules
  - Aircraft detection
  - Take off & Landing counts
  - Tail number capturing
  - Aircraft identification

N798BF

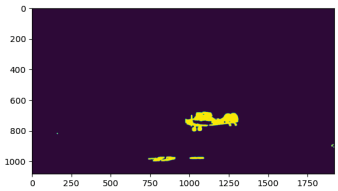
12

Machine Vision Detailed Framework

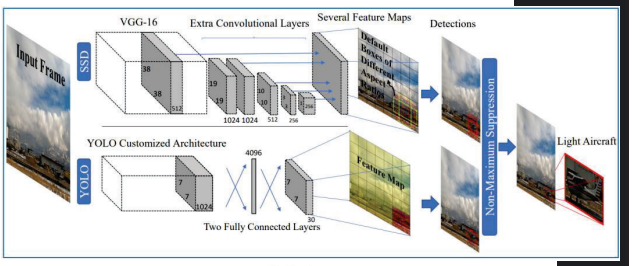


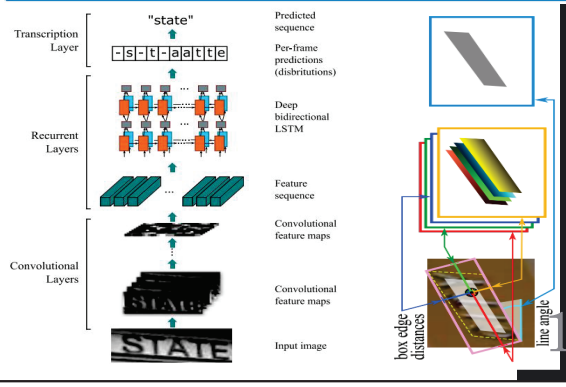
Operation count +1
Operation type: Landing
Aircraft ID: N787HD

Machine Vision Algorithms (summarized)



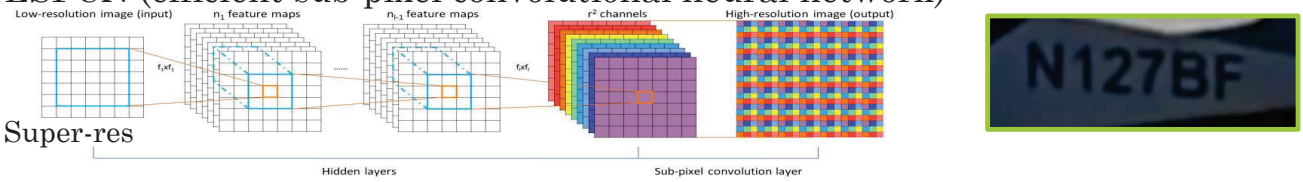
Module	Algorithm	Method
Motion Detection	Blob Analysis	Gaussian Mixture-based Background Analysis
Aircraft Detection	YOLO SSD Haar Cascade	Deep Neural Networks
Aircraft Tracking	MOSSE CSRT	Correlation-based Trackers
Pre-Processing	ESPCN	Super Resolution (Deep)
Tail Number Detection	TextBoxes EAST	Deep Neural Text Detection Networks
Tail Number Recognition	CRNN Tesseract	Deep Neural Sequence Recognition Networks
Aircraft Identification	Joint Probabilistic Analysis 1 & 2	Conditional Probabilistic String Analysis

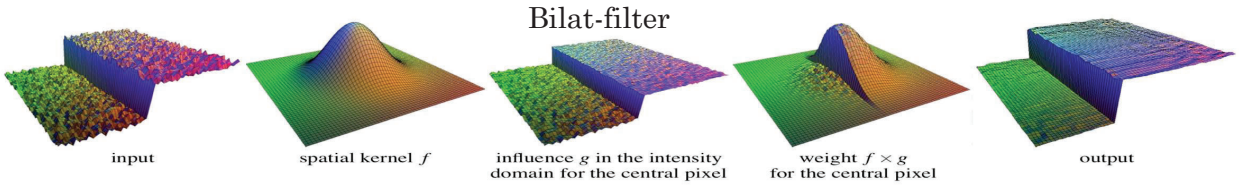




Super resolution & Bilateral filter

ESPCN (efficient sub-pixel convolutional neural network)

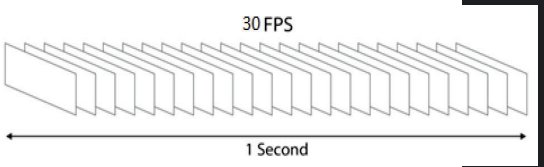




15

Why joint probabilistic analysis

- Each operation footage has between ~150 to ~300 frames
- Each frame ----- > one detected tail number
- Errors:
  - noise and blurry effects
  - D looks like 0, 4 and A, S and 5, T and 7 and 1,....
  - Occlusion: some hidden and unread characters
- 150-300 tail number recognition for one operation
- Joint Probabilistic Analysis:



16

Joint Probabilistic Analysis (JPA)

N287SC → N2875C

N281SC

N287SC → N2875C

N2875O

N2815C

- Why do we need JPA at all?
  - Because there are several recognition per operations
- Why do we need solution 2?
  - Solution 2 is a complementary solution for cases of misrecognition by solution 1

Joint Probabilistic Analysis solution 1

13 votes N2878C
8 votes N2875C
5 votes N287SC
5 votes N28TSO
3 votes 287SG
2 votes N2815C
1 votes 28T5C
1 votes N75C

ICAO tail number normative check

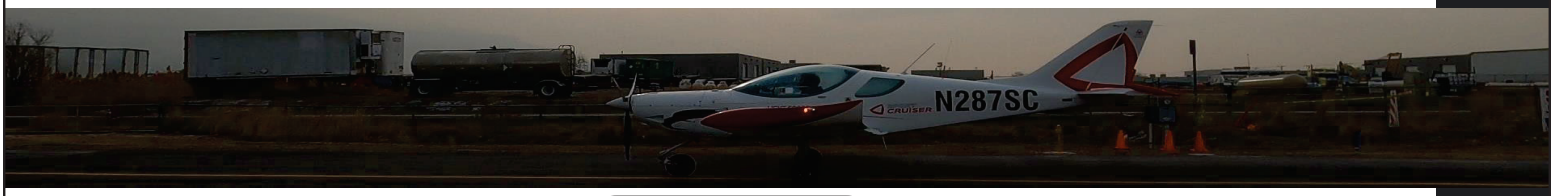
13 votes N2878C
8 votes N2875C
5 votes N287SC
3 votes 287SG
2 votes N2815C
1 votes N75C

Airport Data-base

String Analysis

5 votes N287SC
2 votes N2815C
1 votes N75C

Joint Probabilistic Analysis solution 1



13 votes N2878C
8 votes N2875C
5 votes N287SC
5 votes N28TSO
3 votes 287SG
2 votes N2815C
1 votes 28T5C
1 votes N75C

ICAO tail number normative check

13 votes N2878C
8 votes N2875C
5 votes N287SC
3 votes 287SG
2 votes N2815C
1 votes N75C

Airport Data-base

String Analysis

Find the Closest one

Joint Probabilistic Analysis solution 2

$$p(T/c) = \frac{\sum_{j=1}^{N} p(c_j/T_{(j)})}{N}$$

$$\text{argmax}_{T \epsilon \Psi} \prod_{f=1}^{F} p(T/c)$$

Database

…
N188SX
N287SX
N287SC
N463SC
…

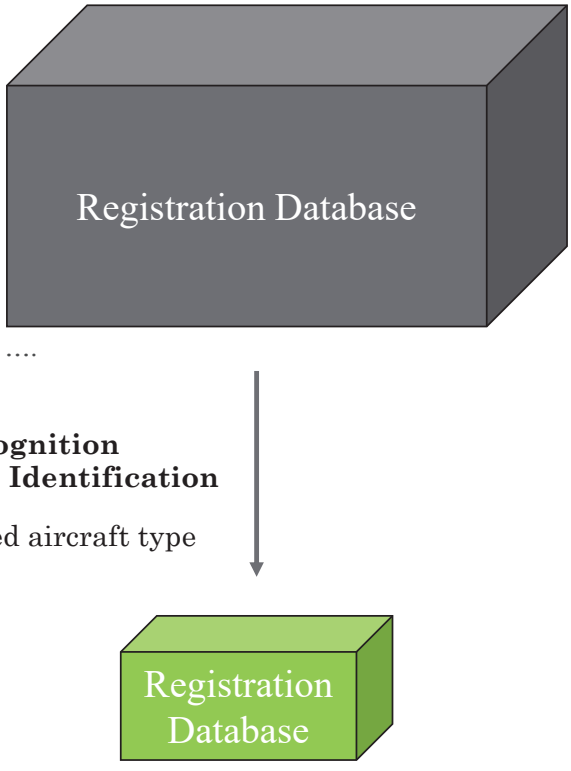
N2B75C

68%	52%	49%	33%	44%	38%
N	2	B	7	5	C
18%	11%	37%	24%	41%	28%
M	X	8	1	S	G
7%	5%	11%	9%	5%	17%
V	9	6	I	3	Q

Is there any other way to increase the system reliability?

FAA Database

- ~ 300,000 Registered Aircraft in the U.S.
- Similar registered N-Numbers (Tail Numbers)
  - e.g., N127BF could be seen as N1278F or N121BF or ….
- Solution? **Aircraft Type/Model Recognition Prior to Aircraft Tail Number Identification**
- Removes irrelevant tail numbers to the recognized aircraft type



FAA REGISTRATION DATABASE

Aircraft Reference file by Make/Model/Series Sequence

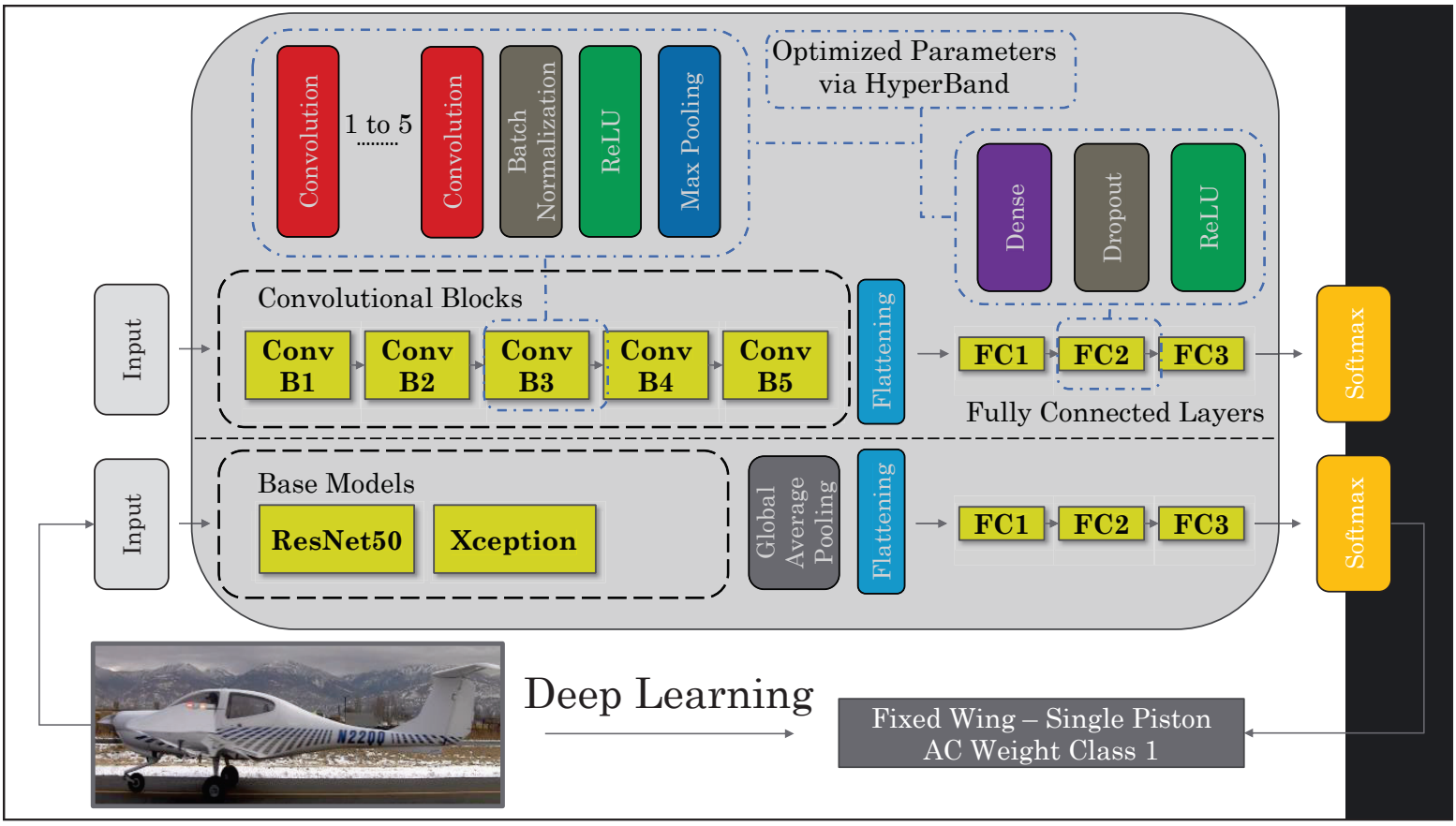
CODE, MFR, MODEL, TYPE-ACFT, TYPE-ENG, AC-CAT, BUILD-CERT-IND, NO-SEATS, NO-ENG, AC-WEIGHT, SPEED, TC-DATA-SHEET, TC-DATA-HOLDER

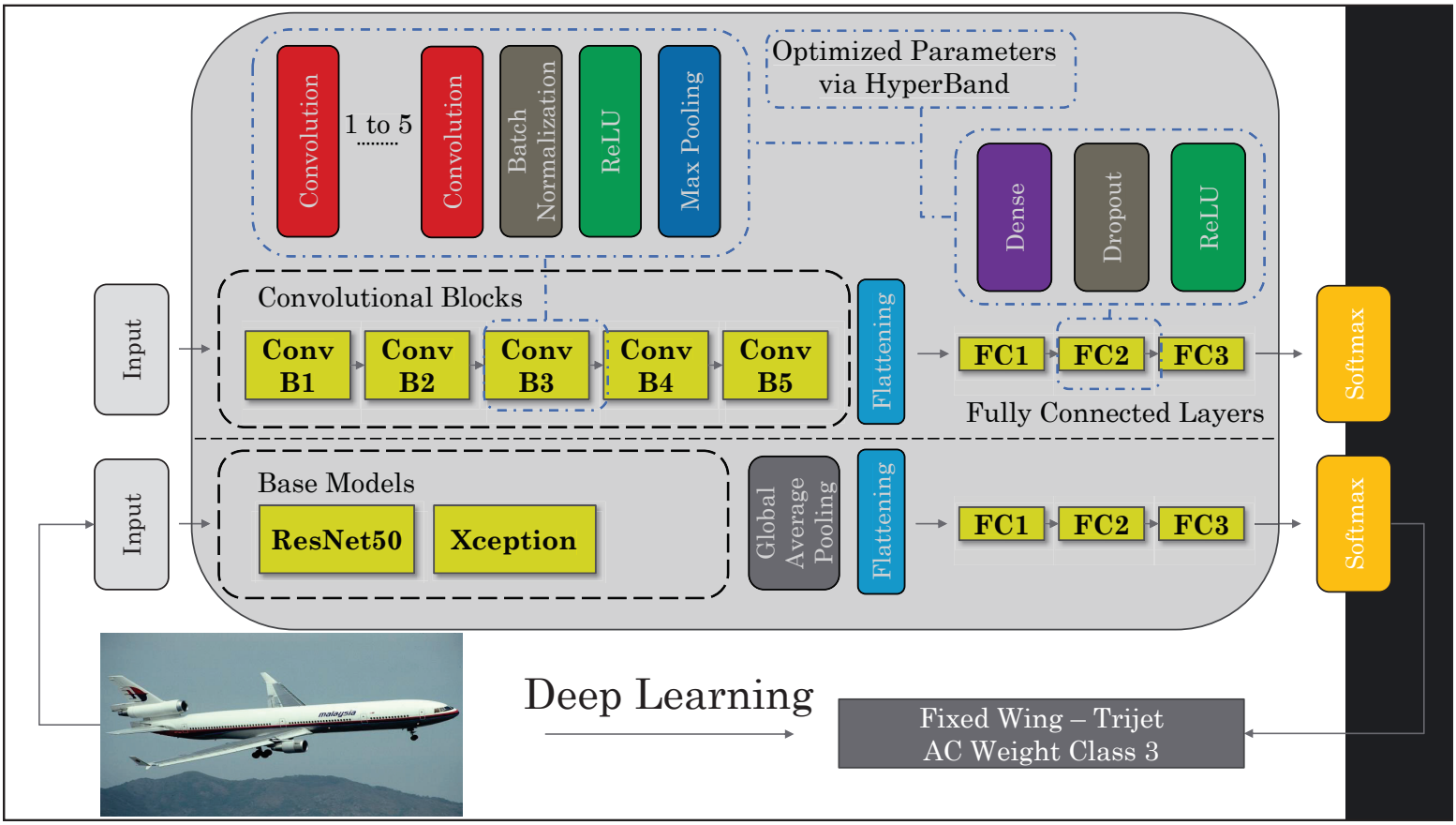
Aircraft Registration Master file

N-NUMBER, SERIAL NUMBER, MFR MDL CODE, ENG MFR MDL, YEAR MFR, TYPE REGISTRANT, NAME, STREET, STREET2, CITY, STATE, ZIP CODE, REGION, COUNTY, COUNTRY, LAST ACTION DATE, CERT ISSUE DATE, CERTIFICATION, TYPE AIRCRAFT, TYPE ENGINE, STATUS CODE, MODE S CODE, FRACT OWNER, AIR WORTH DATE, EXPIRATION DATE, UNIQUE ID, KIT MFR, KIT MODEL, MODE S CODE HEX

Visually Perceivable Information

TYPE AIRCRAFT
TYPE ENGINE
MFR, MODEL
NO-ENG
AC-WEIGHT

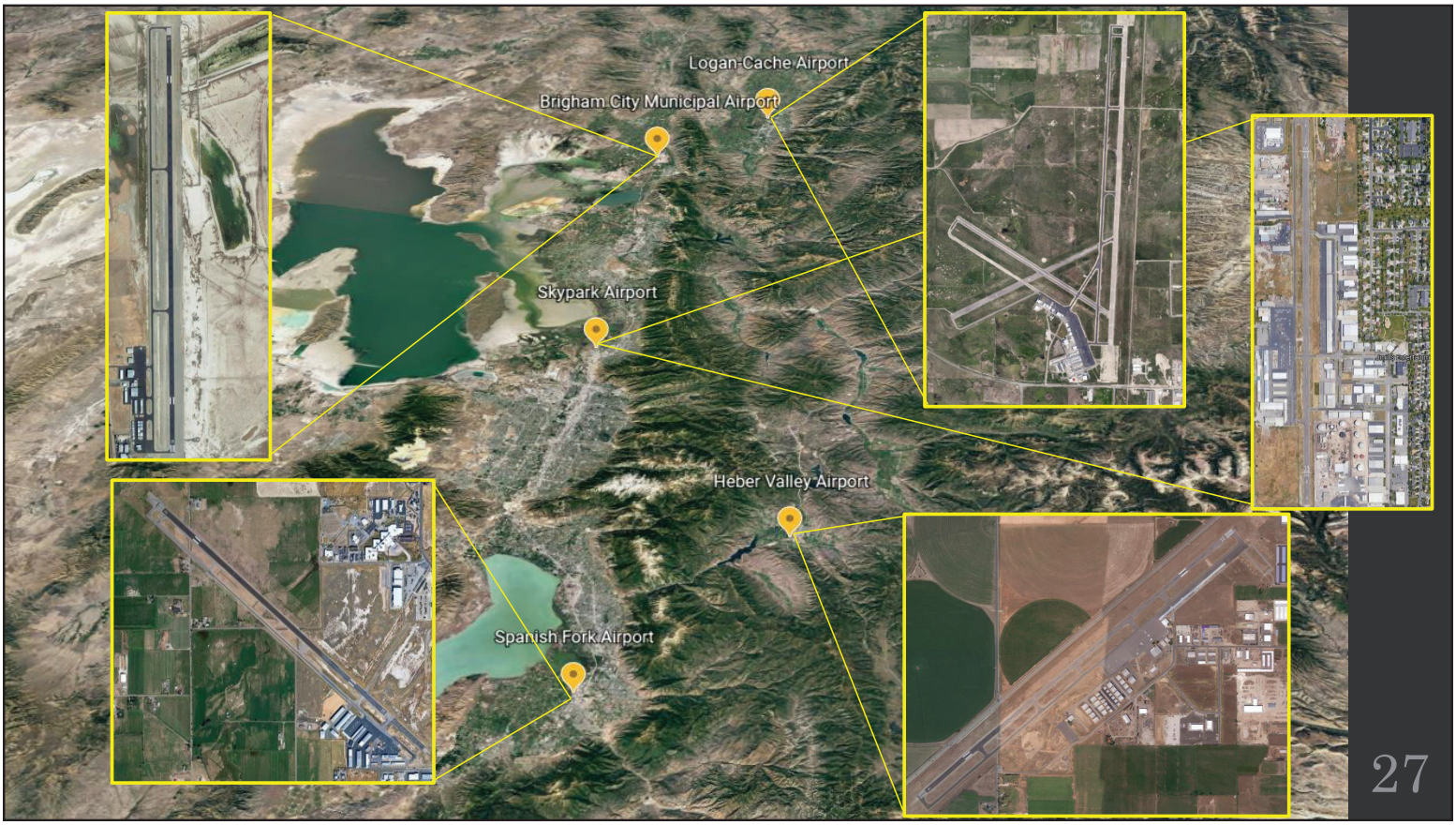




Case Studies: Test Locations

- Weather Conditions:
  - Snowy
  - Cloudy
  - Sunny
- Time
  - Day-time
  - Night-time
- Locations
  - 5 public-use Utah airports

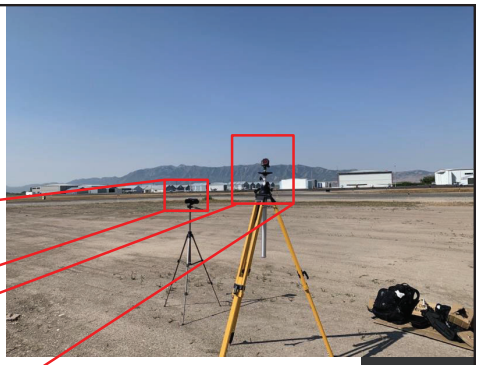
26



Case Studies: Experimental Setup

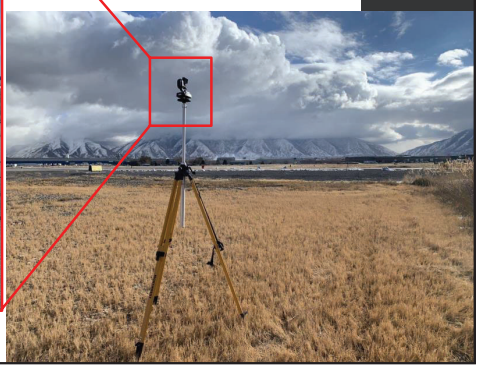
- **29 data collection sessions**
- 3 cameras
- Video configurations:
  - HD resolution
  - ~30 fps

CamCorder



FujiFilm XT-30

GoPro Hero 8

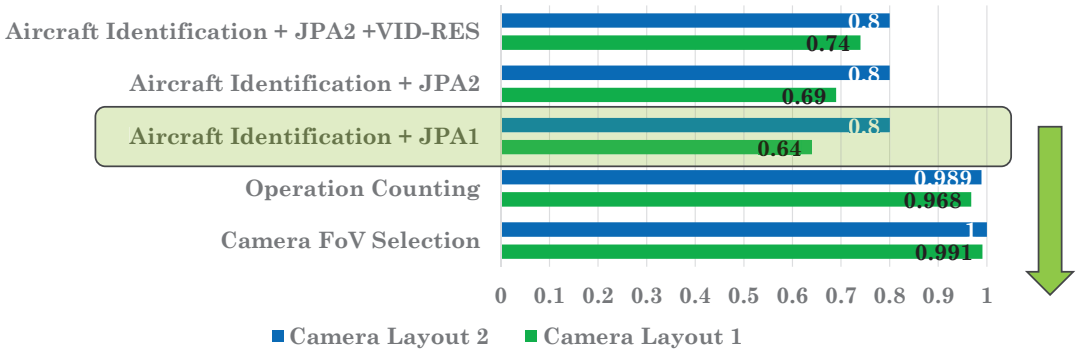


Case Studies: Experimental Setup

- The traffic was recorded separately during the data collection time using a **radio** and by direct **observation**

29

System Performance Accuracies



		Layout 1	Layout 2
% Correctly Identified		64%	80%
% Unidentified	Aircraft with no printed tail number	7%	6%
	Not visible (small, cluttered, unclear tail numbers)	15%	9%
	Software error	14%	5%

30

System Performance Limitations

- Not OCR-friendly Tail Numbers

small | distorted | cluttered | no tail number

- Night Time Operations
  - Runway lighting alleviate the nighttime visibility issues (operation count)
  - Infrared night vision cameras for layout 2 in airports with no lighting
  - Lower frequency of aircraft operations mitigate the low visibility issue (The ACRP Report 129)

ACRP Report 129 "Evaluating methods for counting aircraft operations at non-towered airports"

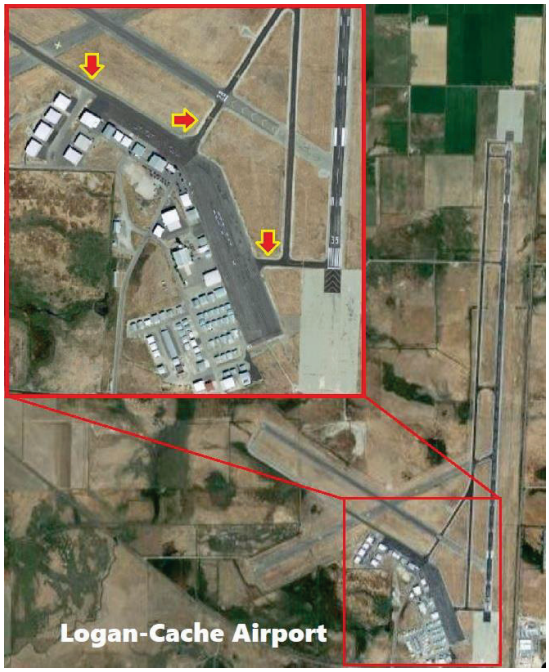
31

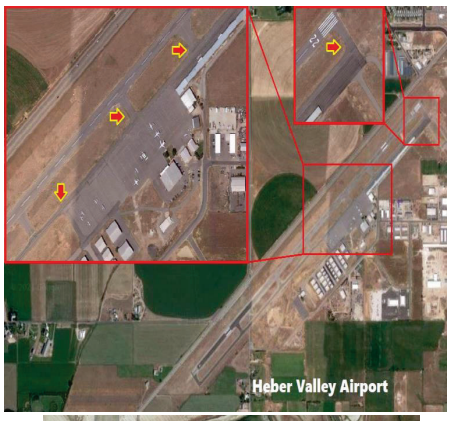
Implementation

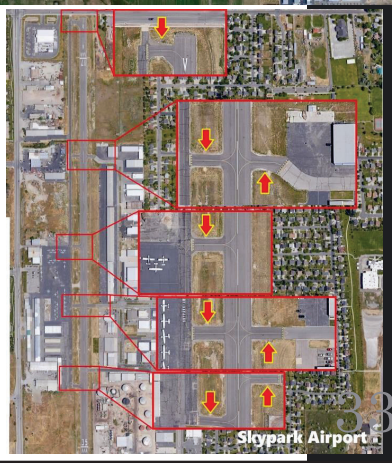
- Optimum placement of the cameras at the five test location airports
  - Camera Layout 1:
    - Two cameras for each runway lane
    - Counts Departures and Landings
    - Less accurate identification
  - Camera Layout 2:
    - One camera at each strategic passage
    - Counts Departures, Arrivals, Touch&Goes
    - More accurate identification

32

Implementation



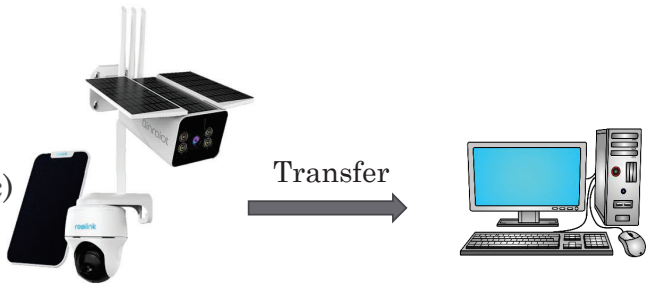




33

Implementation
Record & Process

- Recording Setup
  - Solar-powered camera
  - > 2-3x digital zoom (layout 1 specific)
  - > 1080x1920 video resolution
  - > 24 fps (layout 1)
  - > 10 fps (layout 2)



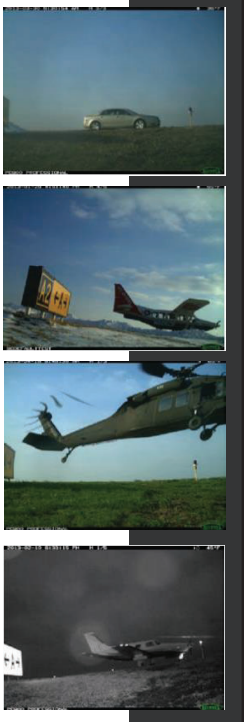
- Processing the Recorded Video
  - Computer with an NVIDIA GPUs
  - OpenCV installed

34

Associate Costs

Option	Base (WIFI)	Cellular	Solar
Implementation/initial setup cost per project	$1,500		
Camera (outdoor rated, PTZ)	$500		+$600
Installation	$500		+$450
Data (maximum 1000 flights per month for cellular option)		+$6400	
AiViON™ 8-month License	$3,000		
Total (for two camera system)	$11,900	$24,300	

Implementation Spin off Benefit (S/TC)



- Accelerating aircraft tallying via the current security/trail cameras

Future Research
Edge computing

NVIDIA Jetson Nano Developer Kit + Waveshare Raspberry Pi HQ Cam + Waterproof Solar Panel PowerStation

Hardware Assembly

Electronic Engineering

Software Adjustment

Pilot Experiments

Industry Mentor

Standalone Device

37

Acknowledgment

- Mountain-Plains Consortium
- Utah Department of Transportation

Airport Authorities:

- Steve Durtschi (Skypark Airport manager)
- Tyler Pugsley (Brigham Municipal Airport manager)
- Cris Child (Spanish Fork Airport assistant manager)
- Travis Biggs (Heber Valley Airport manager)
- Dakota Mahan (Heber Valley Airport assistant manager)
- Lee Ivie (Logan-Cache Airport manager)

Student Team Members:

- Chandler Cross
- Ali Hassandokht
- Behnam Sherafat
- Zhongming Zhiang
- Vitoria Bini
- Cyrus Safai

TRANSPORTATION LEARNING NETWORK

A partnership with MDT•NDDOT•SDDOT•WYDOT and the Mountain-Plains Consortium Universities

Thank you for participating!

Please take a moment to complete the evaluation included in the reminder email.

We appreciate your feedback.

Contact Information

Chris Padilla
chris.padilla@ndsu.edu
(701) 202-5730

Susan Hendrickson
susan.Hendrickson@ndsu.edu
(701) 238-8646

Shannon Olson
shannon.l.olson@ndsu.edu
(701) 552-0672

Amanda Miller
amanda.jean.miller@ndsu.edu
(701) 515-8774

https://tln.learnflex.net
https://www.translearning.org

Thank you to our partners: