Characterizing National Airspace System Operations Using Automated Voice Data Processing

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Outline

▪ Air Traffic Control (ATC) Voice Data and Speech Recognition

▪ Use Case: Approach Procedure Utilization

▪ Other Applications/Use Cases for Voice Data

▪ Future Enhancements
## Scope of Research on Air Traffic Control (ATC) Speech

<table>
<thead>
<tr>
<th>Real-Time Speech Recognition</th>
<th>Real-time safety and efficiency applications</th>
<th>Sim-pilots</th>
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<tbody>
<tr>
<td>Post-Operations Speech Recognition</td>
<td>Post-operations data analysis – both large-scale and individual event review</td>
<td>Analyze speech for research or training (e.g., after action review)</td>
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The Value of Large-Scale Automated Voice Data Processing

- Understanding the National Airspace System
- Exploring interesting events
- Demonstrating benefits of new capabilities
- Preparation for field test & demonstration of real-time systems
Unique Characteristics of Large-Scale Automated Voice Data Processing

- **List of challenges related to acoustics**
  - Pilot, controller, and intercom audio mixed together
  - No push-to-talk information
  - Audio quality is lower because of additional lossy data conversions

- **List of challenges related to scale**
  - Given the number of facilities and position/sectors, it isn’t practical to manually configure sites-specific data
    - Over 40,000 different waypoint and procedure names
  - Complexity of working in a highly distributed computing environment
  - Overhead associated with managing large-scale data processing

- **List of benefits related to processing audio after-the-fact**
  - Processing response-time not as critical
  - Access to context information (e.g., arrival time, full track)
Processing Workflow

1. Source Audio
2. Ingest Audio
3. Segment & Identify Speaker Role
4. Convert Speech to Text
5. Semantic Parse
6. Extract Aircraft Identifiers
7. Fuse with Surveillance
8. Flight Data
9. Surveillance Data

MITRE’s voice data analysis capabilities
Remote access to Federal Aviation Administration (FAA) recordings of radio communications from live operations:
- 129 FAA ATC facilities
  - all ARTCC, most major towers and TRACON
- More than 200,000 hours of silence-reduced audio/month
- Approximately 1 TB data/month
- 2-3 billion transmissions/year
Identifies new audio files and distributes them into Hadoop workflow:

- Extracts audio metadata from filename: *facility, recorder channel, controller position, start and end times*

Partitions data by date and facility for processing
Component is built on Carnegie Mellon University’s Sphinx4:
• Applies an acoustics-based approach to roughly identify where transmissions begin and end
• We custom trained model to classify speaker as pilot or controller
• Refines transmission endpoints after classification

Accuracy between 85% to 90% across facilities
Component is built on the Kaldi speech recognition engine maintained at Johns Hopkins University:
• Uses MITRE-created Deep Neural Network-based (DNN) acoustic model and statistical language model
• Trained on ~500 silence-reduced hours of transcribed controller-pilot audio from variety of FAA sources
• Models trained outside workflow on high performance cluster with GPUs

<table>
<thead>
<tr>
<th>Speaker Role</th>
<th>Word Accuracy (20 ATC facilities)</th>
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<tbody>
<tr>
<td>Controller</td>
<td>83% - 95%</td>
</tr>
<tr>
<td>Pilot</td>
<td>75% - 89%</td>
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Input:

Controller

delta eight thirty two turn left heading two five zero join the i l s runway two five right approach

Output:
Flight data consists of transfer, arrival, and departure messages from FAA automation:
- Determine list of aircraft likely on frequency
- Adjust extracted aircraft ID to context-like aircraft ID

Algorithms use human-defined parse rules for concept extraction

<table>
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<tr>
<th>Concept Type</th>
<th>Concept Accuracy</th>
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<tbody>
<tr>
<td>Commercial Aircraft IDs</td>
<td>80%</td>
</tr>
<tr>
<td>Approach Clearances</td>
<td>90%</td>
</tr>
<tr>
<td>Takeoff &amp; Landing Clearances</td>
<td>95%</td>
</tr>
</tbody>
</table>
MITRE’s voice data analysis capabilities

Processing Workflow – Fusion

- Source Audio
- Ingest Audio
- Segment & Identify Speaker Role
- Convert Speech to Text
- Semantic Parse
- Fuse with Surveillance

Fuses each transmission using date, time, and extracted aircraft ID to surveillance & flight data pertaining to the same flight
Use Case: Approach Procedure Utilization
Problem/Need for Voice Data

- **Tracking approach procedure usage is important for:**
  - Understanding investment benefit
  - Understanding potential cost savings where procedures are not being used
  - General understanding of the NAS

- **Tracking approach procedure usage with radar data or flight plan can be challenging:**
  - Flight plans do not contain the expected or cleared approach
  - Flights on different approach procedures often have very similar trajectories due to overlays and/or common waypoints

- **Controller-pilot voice communications contain approach clearances**

RNP = Required Navigation Performance, a type of procedure
Problem/Need for Voice Data

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RNP = Required Navigation Performance, a type of procedure
Accuracy

- Each step in the processing pipeline can cause inaccuracy
- We filter records that are likely incorrect, to favor precision over recall
  - Aircraft ID must correspond to a flight that arrived at an airport within that approach facility
  - Detected approach clearance must be within 30 minutes before landing time
- Estimate upper bound of number of flights with no associated approach clearance
  - Compare known arrivals at a given site to the number of approach clearances detected
  - Upper bound was ~20% for most airports
  - General aviation flights made up a substantial share of the missing approach clearances
- Accuracy needs are specific to the use case
Without voice data, we used procedure conformance bounds of 0.12 NM to estimate RNP procedure utilization – always had to caveat results because of similarity between RNP and visual approaches.

Using voice data, we can differentiate between visual and RNP approaches to DCA runway 19.

Results indicate that using track conformance alone resulted in a substantial over-estimate of the number of arrivals that used the RNP approach.

DCA Runway 19 RNP AR Utilization Estimates
July 2017

Number of Arrivals

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<th>Without Voice Data</th>
<th>With Voice Data</th>
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<tbody>
<tr>
<td>1,700</td>
<td>595</td>
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RNP = Required Navigation Performance
LDA = localizer type directional aid, another type of procedure.
Analysis Results: Approach Type by Airport

- Time period: July 2017

- This type of information cannot be derived without voice data analysis
Other Applications/Use Cases for Voice Data

- **Additional approach clearance analysis** – comparison of flight performance (e.g., altitude profiles, speeds) and safety metrics (e.g., final approach overshoot, unstable approach, terrain proximity) between cleared approach types
- **Arrival and departure procedure utilization** – improve understanding of how arrival and departure procedures are used in the NAS
- **Visual separation detection** – identify when pilot-applied visual separation has been established, to inform risk assessment
- **Class B excursions advisories** – understand the information controllers provide to pilots prior to the flight leaving Class B airspace
- **Altitude discrepancies** – understand situations where flights do not comply with controller altitude instructions
- **Missed approach/go around initiator** – identify whether controller or pilot initiated a missed approach/go around
Future Enhancements

- Accuracy improvements for each processing step
- Customization to better support waypoint & procedure name recognition across the airspace system
- Throughput improvements to reduce computing resource costs and allow recomputes to benefit from accuracy improvements
- Enhancements to support rare-but-important event/speech handling
- Dialogue processing to fill in implied information
Questions?
Backup
Method

- Processing workflow provides aircraft IDs and semantic tags for approach clearances
- But:
  - Semantic tag is speaker role-agnostic, so we need to select just the controller transmissions
  - One flight may be issued multiple approach clearances, so we need to select the last one
  - Arrival airport is not mentioned, so we use aircraft ID detection to make sure we are including appropriate transmissions
- Note that we could use site-specific control position information, but that technique is more difficult to scale to hundreds of airports in the NAS
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<th>Fiscal Year:</th>
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<td>Outcome Number:</td>
<td>3, 8</td>
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<tr>
<td>PBWP Reference:</td>
<td>3-4.1-1, 8-4.1</td>
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