**Regional Focus** 



# Advancing ATM Research & Development in the Asia Pacific -Spotlight on ATMRI

Thursday 01 October 2020 09:00 – 11:00 CET

## Moderator



## Mr. Hai Eng Chiang Director Asia Pacific Affairs

CANSO

**Regional Focus** 



Advancing ATM Research & Development in the Asia Pacific -Spotlight on ATMRI

## **Speaker**



## Professor Vu Duong Director

**ATMRI** 





Air Traffic Management Research Institute

Presentation at CANSO Webinar Regional Focus ADVANCING ATM R&D in the Asia Pacific Oct 01, 2020

Vu N. Duong, PhD Professor of Aerospace Engineering Director, Air Traffic Management Research Institut

## Background

Established since 2013 as a CAAS-NTU joint-research and experimental centre, initially to:

- Maintain Singapore as a leading air hub
- Contribute to regional ATM modernisation
- Conduct high-quality ATM research
- Nurture talents for the future in Singapore



## **Objectives 2023**

To become a world **leader in AI & Data Analytics Research** for ATM

To become a world's **Center of Excellence** for UAS/UAM Traffic Management Research

To become the **Regional Hub** for ATM studies

To become a world **leader in innovation to** enhance ATM operations



3

4

## **Research Programmes**





### Programme 1 AI & Data Analytics for ATM

**Director: Assoc Prof Sameer Alam** 

3 objectives:

- Hybrid Al-Human ATC operations & system
- Suite of Al algorithms & Machine Learning models for augmented ATCo cognition
- Human-Al Chatbot system for ATM



### Programme 2 UAS&UAM Traffic Management & Systems Director: Prof Low Kin Huat

4 objectives:

- Deliver Traffic Management solutions in urban environment
- Study integration of UAS with other mobility means into urban airspace
- Study applications of enabling technologies to enhance safety & reliability of flight operations
- Conduct field tests of developed solutions



### Programme 3 Regional ATM Modernisation Act. Prof Vu Duong

- 3 objectives:
- Explore into advanced ATM concepts for Singapore and ASEAN
- Publish reports on ASEAN Traffic Growth and on ASEAN Statistics & Analysis
- Conduct simulation exercises for short-term regional needs, in coordination with CAAS for ICAO initiatives



### Programme 4 Exploratory Studies & Emergent Technologies PI: Prof. Vu Duong & Prof Lye Sun Woh

**Objectives:** 

- High-risk high-return investigations aiming breakthrough innovations
- Human-centric Digital Technology Integration including human factors/roles in data-driven paradigm



### Some examples:

- 1. Blockchain for cross-region ATM (Assoc Prof Wee Keong Ng)
- 2. Blockchain-based decentralized multi-agent system for Regional ATFM (Dr Don Ta)
- 3. Machine-Learning for integrated departure & arrival surface movement optimization (Prof Vu Duong).
- Using concurrent fMRI-TMS to measure and calibrate the trust and distrust ATCO have for autonomous systems (Prof Vu Duong)
- 5. Visual detection of drones and small moving objects at Airports Airside (Prof Vu Duong)
- 6. Real-time Neuro-visual Situation Awareness Monitoring System for Controller Operational Performance Behaviour (Prof Lye Sun Woh)



## **Current Resources**

#### • Facilities

- Fast-time simulators: AirTOp and SAAM
- Real-time simulators: NARSIM (6 CWP's) and ESCAPE Light
- 360-degree Tower Simulator with 6 CWP
- 15 Pseudo-Pilots Positions



**RADAR Simulator** 

- Staff
  - 38 Researchers (16 Singaporeans +PR)
  - 18 full-time PhD Students on-site
  - Involving 8 Faculty Members (4 full-time)



360° TOWER Simulator



## Thank you for your attention



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## Speaker



## Prof. Sameer Alam

Associate Professor at the School of Mechanical and Aerospace Engineering

Nanyang Technological University



### A Hybrid Al-Human Air Traffic Management System

Sameer Alam PhD Associate Professor & Deputy Director, Air Traffic Management Research Institute, School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore

## Can you drive using back view mirror?



Image Source: https://lifebeyondnumbers.com/look-back-life/

Many ATM Systems depend on models that are <u>inadequate representation of reality</u> good for predicting the past but poor at predicting the future.

World leading Economist failed to predict 2008-2010 financial crisis. Relied on models based on historical statistical data that cannot adopt to new circumstances.

## ATM: A Complex Adaptive System



## A Hybrid Man-Machine Approach

### Combine the Expert Judgement with Relevant Data

- Data tells real life.
- Historical data contains human intelligence.
- START (when you ready)
  - Extract human actions (intelligence) from data.
  - Convert the data into patterns
  - Use these patterns to predict actions.
- REPEAT (forever)



A Hybrid Al-Human ATM System

## A Hybrid Al-Human ATM System

- Learning and Predicting Controller Strategies
- Surface Movement Optimisation
- Identifying, Learning and Detecting Unstable Approaches
- Conflict Detection & Resolution

### Learning and Predicting Controller Strategies

Can a machine learn planning ATCo strategies, from historic air traffic data, to predict an aircraft 4D trajectory at Sector Entry point?



## Extracting ATC strategies: Action-Prediction Model

- Modelled as supervised learning problem.
- Target variables are planning controller actions, explanatory variables are the aircraft 4D trajectory features.
- The model is trained on six months of ADS-B data (en-route sector)
- Generalization performance assessed using cross-validation, on the same sector.



### **Action-Prediction Model: Results**

Longitude

- Model for vertical manoeuvre actions prediction accuracy of ~99%.
- Model for speed change and heading change action: prediction accuracy of ~80% and ~87% respectively.
- Model for predicting strategic actions (altitude, speed and course change) achieves an accuracy of ~70%

For 70% of flights, planning Controller's action can be predicted from trajectory information at sector entry position.



### A Hybrid AI-Human ATM System

- Learning and Predicting Controller Strategies
- Surface Movement Optimisation
- Identifying, Learning and Detecting Unstable Approaches
- Conflict Detection & Resolution

## Surface Movement Optimisation

Can a Machine learn to plan conflict-free taxiway routes with unimpeded taxi time, and predict congestions?

- Modelled as Classification problem
- Two months A-SMGCS data at Changi Airport (42,427 flights).
- A spatial-temporal graph-based trajectory representation for Gate-to-Runway holding point ATC preference model with taxi-speed prediction.
- Spatial-temporal representation is used to predict probability of crossing at intersection to estimate Hot Spots.



## Surface Movement Optimisation





## A Hybrid AI-Human ATM System

- Learning and Predicting Controller Strategies
- Surface Movement Optimisation
- Identifying, Learning and Detecting Unstable Approaches
- Conflict Detection & Resolution

## Identifying, Learning and Detecting Unstable Approaches

Can a Machine learn an aircraft approach profile and flag an unstable approach for Go-Around?



## Learning Unstable Approaches

- A data-driven framework to learn the aircraft 4D trajectories in the final approach phase and its causal relationship with other factors.
- An interpretable probabilistic bound of aircraft parameters that can quantify deviation and perform real-time anomaly detection.



### **Real-Time Unstable Approach Detection**



## A Hybrid AI-Human ATM System

- Learning and Predicting Controller Strategies
- Surface Movement Optimisation
- Identifying, Learning and Detecting Unstable Approaches
- Conflict Detection & Resolution

## **Conflict Detection and Resolution**

#### Can a Machine learn to resolve conflict from ATCo conflict resolution actions?



## Acquire ATCO's resolutions through an interactive interface



preference-based reinforcement learning



AI model suggest advisory for unseen scenario with high ATCO conformance

## Learning from Humans (Realistic Scenario)

- An interactive simulator to collect ATC's resolution for different generated scenarios.
- Use historic Conflict Resolution strategies from ADS-B data







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## Learning from Humans (Abstract Scenario)

- An interactive simulator to collect ATC's resolution for different generated scenarios.
- A machine learning model to learn controller decisions


# Reflection

- To handle air traffic growth, AI is gradually integrated into ATM systems to aid ATCs in performing higher-order cognitive and safety-critical tasks.
- An effective approach is Hybrid AI-Human ATM System where the Machine learns the causal patterns in human decision making.
- To implement a Hybrid AI-Human ATM System we need to coteam AI with humans for effective collaboration, communication and trust.

### Thank You



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Advancing ATM Research & Development in the Asia Pacific -Spotlight on ATMRI

# Speaker



**Dr. John Wang** Assistant Programme Director of Programme 2 (UAM/UTM)

Air Traffic Management Research Institute



### **ATMRI Programme 2:**

Urban Aerial Transport Traffic Management & System

**Program Director: Prof Low Kin Huat** 

Presenter: Dr. C.H. John Wang 01 Oct 2020

### Outline

- Organization
- Existing UTM & UAM ConOps
- Singapore Specific Challenges
- UAS Risk Near Aerodromes
- Development of UTM ConOps for Singapore
- Next Steps

## Organization



#### **UTM & UAM Concept of Operation** Existing ConOps — a global view on current progresses

#### "UTM" ConOps



2020 NASA UTM v2.0

Urban Air Mobility (UAM)

2020 NASA UAM v1.0

Concept o Operat



Unmanned Aircraft System (UAS) Traffic Management (UTM)

2018 NASA UTM v1.0



The Future of Transportation White Paper on **Urban Air Mobility** Systems By EHang Jan 15, 2020

2020 Ehang UAM White paper







2017 DLR Blueprint

Existing UTM & UAM ConOps describes the essential conceptual and operational elements associated



2019 SESAR U-Space





2018 Airbus Blueprint

.....

#### "UAM" ConOps



#### UTM & UAM Concept of Operation Finding the Appropriate ConOps for Singapore



https://www.unmannedairspace.info/uncategorized/singapores-caasdevelop-uas-traffic-monitoring-system/

• Limited available airspace for UTM & UAM operations



https://www.youtube.com/watch?v=Fz5s1ZSZusY

- High population density and densely distributed high-rise buildings
- Challenges of developing UTM & UAM in Singapore
- The ConOps proposed for Singapore context would need to solve these challenges by adopting emerging technologies and effective management.

# **Public Perception to UTM in Singapore**

- Survey with n= 1050
- General acceptance to drone
  usage in Singapore
  - Higher acceptance to drone performing government work (S&R, disaster management, etc.)
  - Lower acceptance to air-taxi and photography
  - Higher acceptance for usage in industrial area and lower in residential
- For residential area, MED1 > MED2. Opposite for business, industrial, and recreational areas.



### **Risk Analysis of UAS Intruding into Aerodrome**

#### Establishing the risk based alert boundaries for aerodrome

- Interface to generate risk-mapping for intruding UAS into Changi Airport
- Heat-map showing collision risk posed by intruding UAS on departure aircraft from Changi Airport runway 02C



# **UAS Collision Severity Modeling**

#### Establishing the safe operation threshold for risk mitigation in aerodrome

 Simulation of engine thrust lost as a result of UAS collision during take-off



Collision simulation with various UAS types



 Analysis of ingestion damage to the fan, Low Pressure Compressor (LPC) and High Pressure Compressor (HPC)



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### **TM-UAS Concept of Operation (2018)**

#### NTU's Traffic Management of Unmanned Aircraft Systems (TM-UAS) Programme



### **Considerations for UTM ConOps in Singapore**



### **AirMatrix Airspace Management Concept**

- Discretize airspace into 15m x 15m x 15m cubes
- Cubes intersecting buildings or un-useable airspace are marked red
- Path planning only performed in the green airspace
  - Modular design allows for implementation of various path-planning algorithms



# Modeling Wake and Encounter Response of Multirotor UAS

Forming the basis for a safe and efficient operation in congested airspace

 CFD simulation of near-field wake vortex using virtual blade model (left) and Overset (right)



 CFD simulation of far-field wake using large eddy simulation



 Wake vortex circulations and positions extracted from the LES simulation



 Software-in-the-loop simulation of wakeencounter by UAS encountering Γ=50 wake



#### **Risk Based Airspace and Traffic Flow Management**

Creating a positive and intelligent ecosystem for UAS operations in Singapore

 Developing interface for all UAS stakeholders to be aware of traffic situations



Providing risk assessment services in all flight phase to ensure safe UA operations.



Enabling flexible airspace management to allow both trajectory-based operation and freeflight operations



Supporting strategic unmanned air traffic flow management by 4D trajectory planning and deconfliction for unmanned.



### **Impact of Noise on Public Perception**

Ensuring public support for the establishment of urban UAS operations

- Noise frequency and amplitude measurement of off-the-shelf recreation UAS
- Correlation between UAS mass, noise frequency, and noise amplitude
- Survey of annoyance level when subjected to various UAS
  - Annoyance level higher with higher amplitude associated with ≥1kg MTOW
  - Annoyance level appears to be similar for smaller UAS



#### Next Step for UTM & UAM Concept of Operation Managing UAS Traffic on the Road to Autonomy

- Emergence of autonomous UAS
- UTM to consider the mix-operation of vehicles with various level of automation and capability in complex environment
- ConOps needed to accommodate
  - Different UAS capabilities
  - Different mission complexities
  - Different operational environments
  - Different C2 availabilities
- The definitions and metrics for categorization is still under active research...



# We welcome your feedbacks!

# **Thank You!**

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# Speaker



# Professor

School of Mechanical and Aerospace Engineering



#### ATMRI Human-Centric Digital Integration Programme

**Prof Lye Sun Woh** 



#### ATMRI Human-Centric Digital Integration Programme



Teaming concerns the effective and successful integration and coordination of individual efforts through team processes and teamwork.

Currently, work on human-machine teaming (some limited forms) have been initiated. Noting the rapid adoption of automation and AI technologies, research into human-machine teaming is urgently needed.

ATMRI human factor programme focuses mainly on

(A) Human-Machine ATM Interactive Studies

(B) Human-Al ATM Studies

# **ATMRI Human-Machine Teaming Studies**

Trust / distrust of autonomous systems

Human-Al Collaboration for Unmanned Traffic Management

Neuro-Physiological Measures for Strategy Identification Cognitive Awareness & Behavior of Spot / Non-Spot Activities

> Real-Time Situation Awareness Assessment

Self Regulation Behavioural Model to Enhanced Controller's Performance

#### Multi-dimensional, objective, empirically derived measure of human-automation trust in ATCOs Principal Investigator: Prof. Vu N. Duong, MAE

#### **Problem Statement**

As technologies (automation and AI) progress and incorporated into ATM systems, trust becomes a vital component in its adoption into the human-machine teaming framework. The level of trust would dictate the use of such technologies by the controllers.



#### **Objectives**

- ✓ To explore a novel use of concurrent fMRI-Transcranial Magnetic Stimulation (TMS) on ATCOs in order to elucidate the relationship between how much trust ATCOs have for their automation tools
- ✓ Study is done to develop a measure of propensity to trust and distrust using an objective questionnaire. To validate the results the previous study with neuroimaging techniques and to isolate the dimensions of trust and distrust using both neuroimaging and neuro stimulation.



Real-Time Neuro-Visual Situation Awareness Monitoring System for Controller Operational Performance Behavior

**Prof Lye Sun Woh** 



# A Recap of Situational Awareness



Situational awareness has been defined as the ability to perceive, comprehend and project the state of an environment (Endsley 1995). Loss of situational awareness while operating highly autonomous systems has accounted for hundreds of deaths in commercial and general aviation (e.g., National Transportation Safety Board (1973, 1979, 1981, 1988, 1990)).

#### Real-Time Neuro-Visual Situation Awareness Monitoring System for Controller Operational Performance Behavior

- Civil Aviation Authority of Singapore (CAAS)
  - Air Traffic Control officers handles <u>1/2 million air</u> <u>traffic</u> (AT) <u>movements</u>.
  - Though affected by Covid-19, over the long run, AT movements expected to and surpass 2019 numbers
- Automation aids via new technologies and procedures are being developed.
  - Loss of Situation awareness (SA)

#### **Drawbacks: Current situation assesment tools**

- Performed offline during training
- Time-consuming
- Subjective
- Shortage of Subject Matter Experts
- Not well suited for system modification

<u>SART</u>: Situation Awareness Rating Technique; <u>SAGAT</u>: Situational Awareness Global Assesment Technique; <u>SPAM</u>: Situation Present Assesment Method ;<u>SASHA</u>: Situation Awareness for SHAPE;



# **Current Approaches & Hypothesis**

0% air traffic characteristic 100% ATCO behaviour

Measuring of ATCO's awareness level:

- Subjective Questionnaires
- Disruptive techniques

<u>Merits</u>

 Better able to distinguish between ATCO

Problems

- Based on ATCO behaviour with vague reference to synchronous air traffic data
- Lack contextual basis for analysis of ATCO

Neural-Visual Situational Awareness Monitoring Behaviour

Proposed Approach: Neuro-Visual Situation Awareness Monitoring System

Use of both air traffic and ATCO data to better capture in real-time and analyse their situational awareness of various tactical monitoring tasks 100% air traffic characteristic0% ATCO behaviour

Use of air traffic characteristic:

- Study of flight trajectory
- Result of ATCO's monitoring activity

#### <u>Merits</u>

- Straightforward, algorithmic data processing
   Problems
- Based on air traffic data with vague reference to actual ATCO behaviour
- Lack understanding how
  ATCO monitored directly

# **Research Question**

Can one use neuro-physiological signals to monitor the general situation awareness (SA) in real time uninterrupted manner of a traffic controller (TC) during task operation?



#### **Neuro-Visual Situation Awareness Monitoring System**



#### Schematic of Brain-Eye Computer Interface (BECI) System for situation awareness

#### monitoring

**Visual attention**: Brain-Eye ability to concentrate its attention on a target stimulus for any period of time. 71





#### Fixation Duration Heatmap of Frame 15, from 00:02:25.497 to 00:02:35.351



# **Results of Preliminary Study**



- The cognitive resource required for ATM monitoring is quite high (>0.6)
- Real-time data of EEG, Average Fixation Count and Duration highlight distinct differences in levels between attentive and non-attentive monitoring activities (individual and collective).
- EEG, Average Fixation Count and Duration can be used as complimentary data sets to gauge and validate the general SA of a traffic controller.

### Thank You

#### **Comments and Queries**

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## Questions

and

## Answers



You are welcome to contact the speakers with any questions you have.

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## Thank you

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