NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

SAAB

Saab – NTU Joint Lab

Tangible Digital Twin with Shared Visualization for Collaborative Remote Tower Operations

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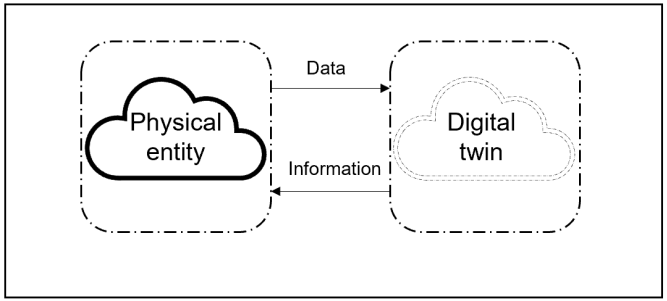
Digital twin

- A digital twin is a digital/virtual replica of a real-world object, system or process.
- **Applications**: real-time remote monitoring, real-time remote control, predictive maintenance, etc.

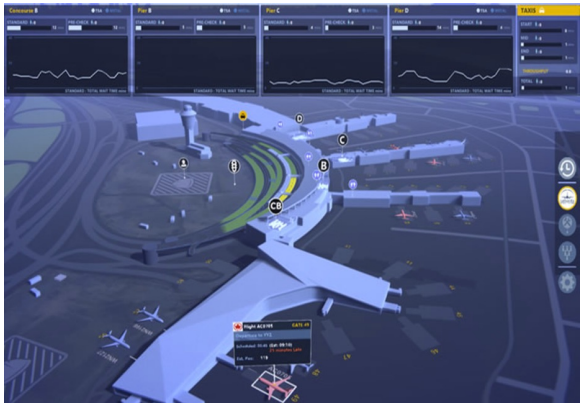


Conceptual Model of Digital Twin

Technologies

- High-performance sensors
- Real-time data transmission
- Data analytics and digital simulation

Digital twin in air traffic management



SITA's digital twin for airport operations control

Thales' digital twin for testing unmanned traffic management

Saab's digital tower

Virtual reality and mixed reality

- Visualization
  - VR: virtual environment with digital content
  - MR: physical environment with digital content merged with physical world

- Interaction
  - Hand-held device: joystick, controller, etc.
  - Human gestures: motion tracking, hand gestures.

VR headset for immersive environment

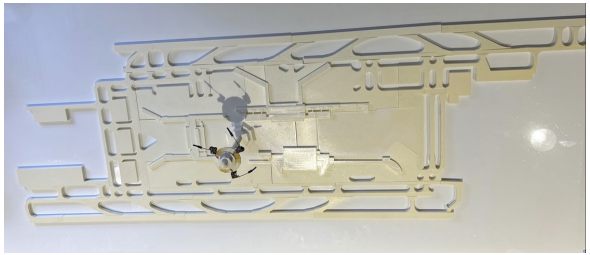
MR headset for see-through environment

Motivations of current study

- Lack of research on visualization and interaction of digital twin from human factors' perspective.
- Advances in virtual and mixed reality (VR/MR) technology.
- This project aims to study design of mixed reality based digital twin to support digital tower operations.

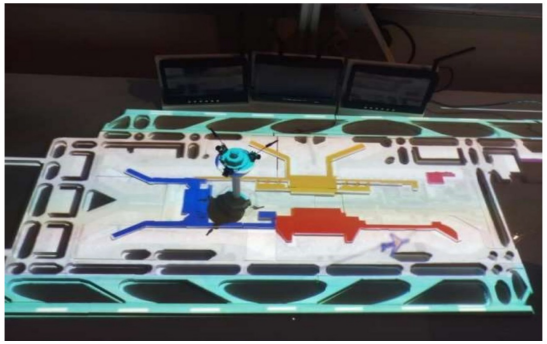
Design 1

- Hardware: Projector + Kinect + 3D printed airport
- MR visualization (Projector + 3D printed airport): **2D digital information** projected to the 3D printed physical airport
- Intuitive interaction (Kinect + 3D printed airport): Hand gestures tracked by Kinect to interact with the system



3-D printed Changi airport model

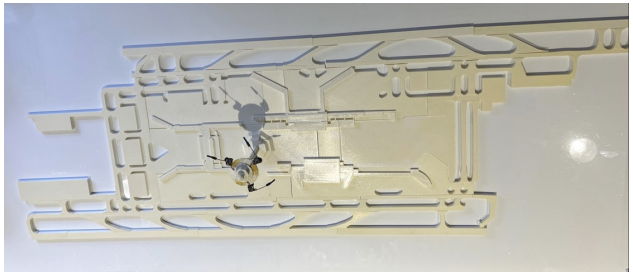
Projection mapping



Visualization of the airport traffic

Design 2

- Hardware: Microsoft HoloLens 2 + 3D printed airport
- MR visualization: **3D digital information** aligned to the 3D printed physical airport.
- Interaction: Finger tapping actions with haptic feedback from tabletop.



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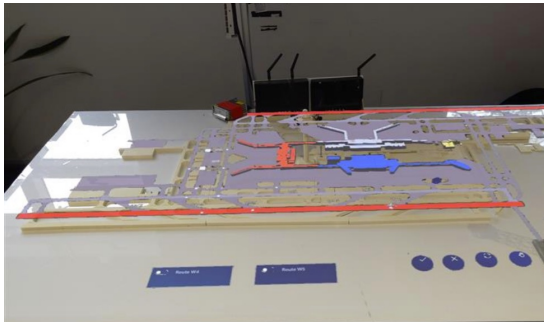


Visualization of the airport traffic from HoloLens' view

Comparisons of the two designs

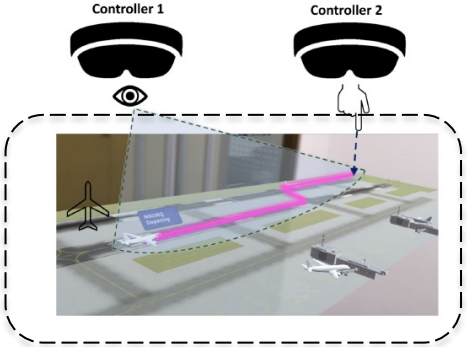
	Design 1	Design 2
Hardware	Projector + Kinect + 3D printed airport	HoloLens 2 + 3D printed airport
Visualization	2D digital + 3D physical, Support shared view	3D digital + 3D physical, Support shared view via multiple HoloLens
Interaction	Hand gestures, hand hovers above the digital aircraft, no haptic feedback	Finger actions, finger taps at digital buttons, with haptic feedback

Next step

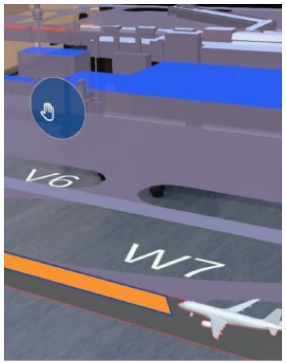
- Human factors evaluation
  - Design **scenarios** for collaborative air traffic management tasks
  - Design **questionnaires** for the final assessments
  - Conduct user study with experienced air traffic controllers

Sample scenario 1

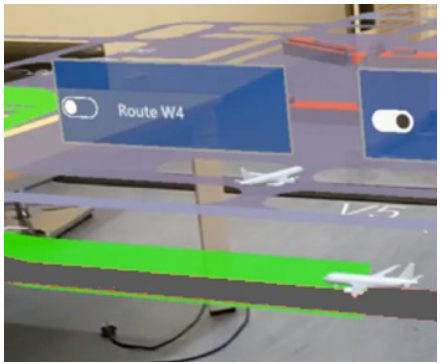
- Introductory-level scenario for collaborative arrival-management task
  - ATCO 1 proposes one specific route, and the ATCO 2 approves it



Shared view for two ATCOs that wear HoloLens



1) ATCO1 proposes a route

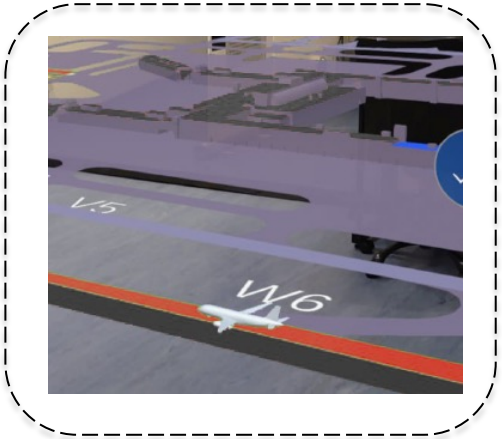


2) The proposed route is approved by ATCO2

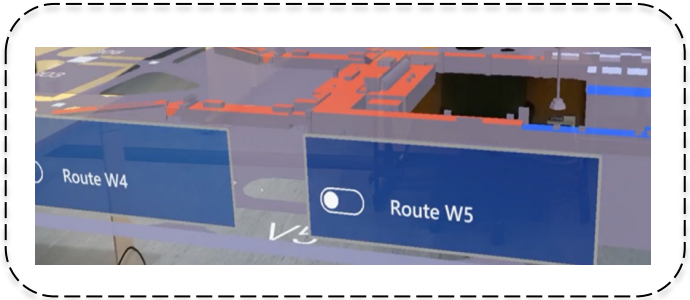
Sample scenario 2

- Mid-level scenario for collaborative arrival-management task
  - ATCO 1 proposed one specific route, and the ATCO 2 rejected it; the ATCO 1 proposed another route, and the ATCO 2 approved it.

1) ATCO1 proposes a route



2) The proposed route is rejected by ATCO2



Holographic buttons for proposing a specific route

Sample scenario 3

- High-level scenario for collaborative arrival-management task
  - Route two aircraft to destination in sequence

- Design more scenarios that simulate ATCOs' daily tasks and non-nominal events
  - Multiple aircraft arrival at different arrival rates
  - Non-nominal events, e.g. aircraft suddenly stops at runway

User study questionnaires

- Situational awareness (SA)
  - China Lake Situational Awareness (CLSA) rating scale (1-10)

Description	Rating
My SA with respect to the task was far too low. I could not perform the task because I did not possess the necessary information.	1
⋮	⋮
My SA with respect to the task was excellent. I was able to perform my task extremely well all of the time.	10

User study questionnaires

- Workload
  - NASA-TLX
- Trust
  - Rate your trust in the system on a three-point Likert Scale (1-Low, 2-Middle, 3-High)
- System usability
  - System usability scale (SUS)
- Open-ended questions
  - Do you think the system will enable you to visualize information without compromising situational awareness?
  - Do you think the system is easy and intuitive to interact with?
  - How likely are you to use the system for low density air traffic control?
  - How likely are you to use the system for medium to high density air traffic control?
  - What are some situations that this system will be particularly useful?
  - What are some situations that this system will be less useful?
  - Do you have any additional comments on the system?

Thank you