HONG KONG CENTRE FOR LOGISTICS ROBOTICS
香港物流機械人研究中心

香港中文大學
The Chinese University of Hong Kong

渠務署
Drainage Services Department

Drainage Services Department Research & Development Forum 2023

Robot and AI Technologies for Inspection Tasks in Smart Cities

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Outline

1. Background
2. Tunnel Defect Inspection: Challenges
3. Development of a Tumbler Inspection Ball (TIB) Robot
4. Experimental Results and Future Research Work
5. UAV-based Outdoor and Indoor Inspections

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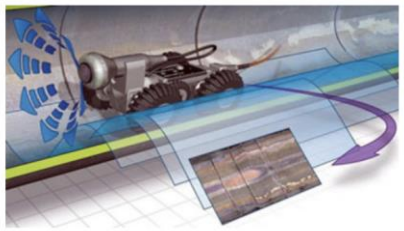
渠務署 Drainage Services Department

» Background: Drainage Service Robots

Inspection of Drainage Pipes

- Integrate high-definition cameras, sensors, and other equipment, realize real-time monitoring and data collection.
- Detect problems such as accumulation of mud, aging, corrosion, rupture and collapse.*

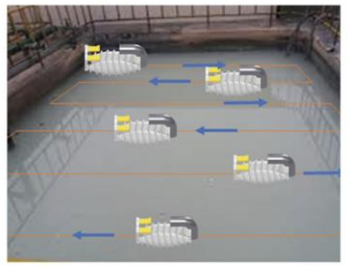


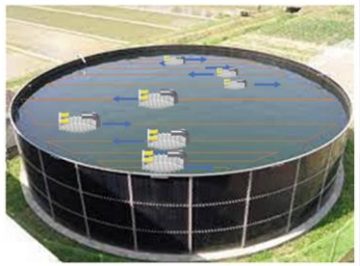
Drainage Pipe Repair

- Carry various manipulators and underwater tools, replacing humans to repair the pipe.+

Water Analysis and Purification

- Real-time collection of water quality data
- water quality data analysis.
- Autonomous water purification.^





Drainage Equipment Inspection

- Based on data collected from the robot, the drainage equipment inspection platform can provide powerful analysis tools for drainage network rehabilitation and maintenance.#

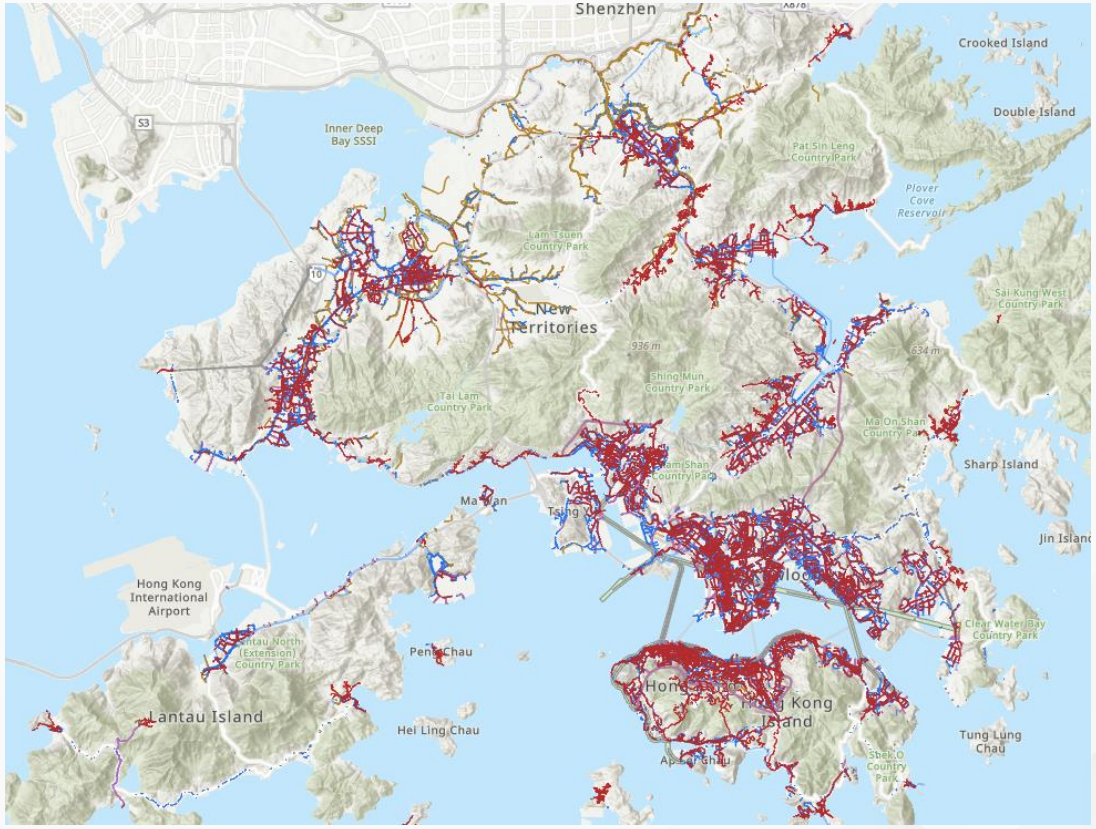
*: Ogai, H., & Bhattacharya, B. (2018). Pipe inspection robots for structural health and condition monitoring. New Delhi, India:: Springer

+: Tugeumwolachot, T., Seki, H., Tsuji, T., & Hiramitsu, T. (2021). Development of a compact sewerage robot with multi-DOF cutting tool. Artificial Life and Robotics, 26(4), 404-411.

^: Hur, J. G., Lim, C. G., & Kim, Y. M. (2022, December). Development of a Robot System for Cleaning Sludge in Industrial Site. In *International Conference on Robot Intelligence Technology and Applications* (pp. 343-350). Cham: Springer International Publishing.

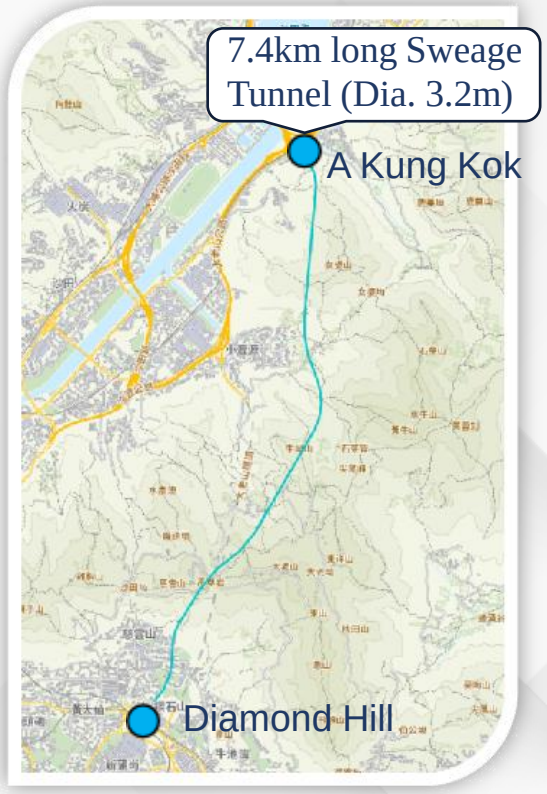
#: Iversen, N., Schofield, O. B., Cousin, L., Ayoub, N., Vom Bögel, G., & Ebeid, E. (2021). Design, integration and implementation of an intelligent and self-recharging drone system for autonomous power line inspection. In 2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)

Background



Pipes and manholes of Hong Kong*

(DSD formed in 1989)



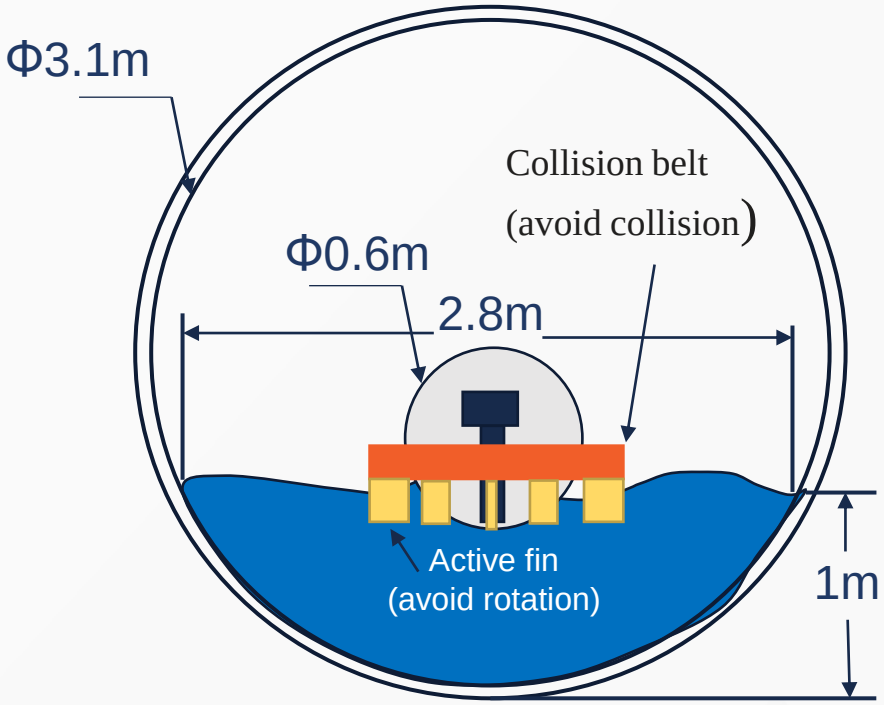
Tolo Harbour Effluent Export Scheme (THEES) tunnel constructed in 1989 (34 years old)**

*: https://livingatlas-dcdev.opendata.arcgis.com/maps/esrihk::drainage-records-of-hong-kong/explore?layer=0&location=22.373681%2C113.999400%2C11.53

**: https://www.dsd.gov.hk/EN/Files/publications_publicity/exhibition_panels/2002/S1_Tolo_Harbour_Effluent_Export_Scheme.pdf

» Background

Tolo Harbour Effluent Export Scheme (THEES) Tunnel



Sewage Pipe Situation

Spec: The underground sewage pipe to be inspected has a length of 7km, water speed (adjustable) around 4m/s, the cross-profile diameter at 3.18m, and the water height at 1/3-1/2 (1-1.5 m height) of the cross-profile.

Tunnel Defect Inspection: Challenges

Reasons

- To identify and fix a problem
- As part of routine maintenance

Challenges

- Long distance inspection
- Safety and health hazards concerns
- Takes months for planning of flow diversion
- Limited time for sewage flow suspension

Current techniques and limitation

Drones

- Power supply – cannot support long distance inspection
- Not able to fly in the environment of high-speed air flow and water import
- Limited distance on signal transmission

Boats

- High flow rate resulting in uncontrollable and unstable motion;
- Risk of flipping over;
- Unpredictable collisions with wall and invert (bottom).

Vehicles

- High flow rate disables vehicles' functionality;
- Unpredictable stairs in the tunnel and unpredictable terrain;
- Long cable for data transmission.

Workers

- Unreliable life support in long distance;
- High risk of biohazard in sewage;
- High temperature brings diseases.

» Tunnel Defect Inspection: Challenges

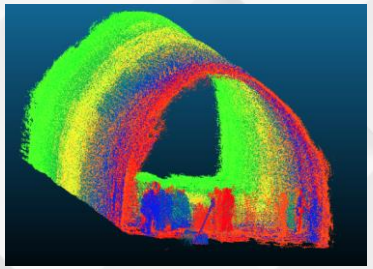
Project Challenges

- Long distance inspection: 7.4km
- High flow rate
- Robot localization and data transmission underground
- Lack of light
- Potential of collision
- No intermediate adit to the tunnel

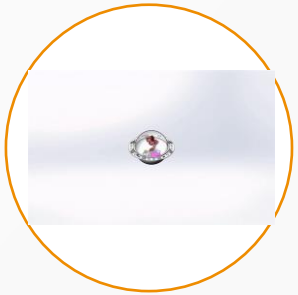
Robot localization

Objectives

- Inspection of tunnel conditions including crack, damage, and other risky conditions
- Detecting the sediment condition



» Development of TIB Robot

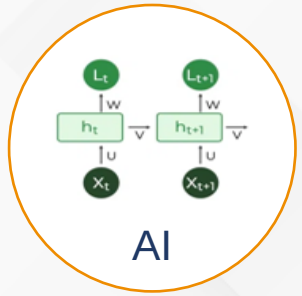


Self-stabilizing Robotic System

+

Ultra-high-Performance Sensors

+

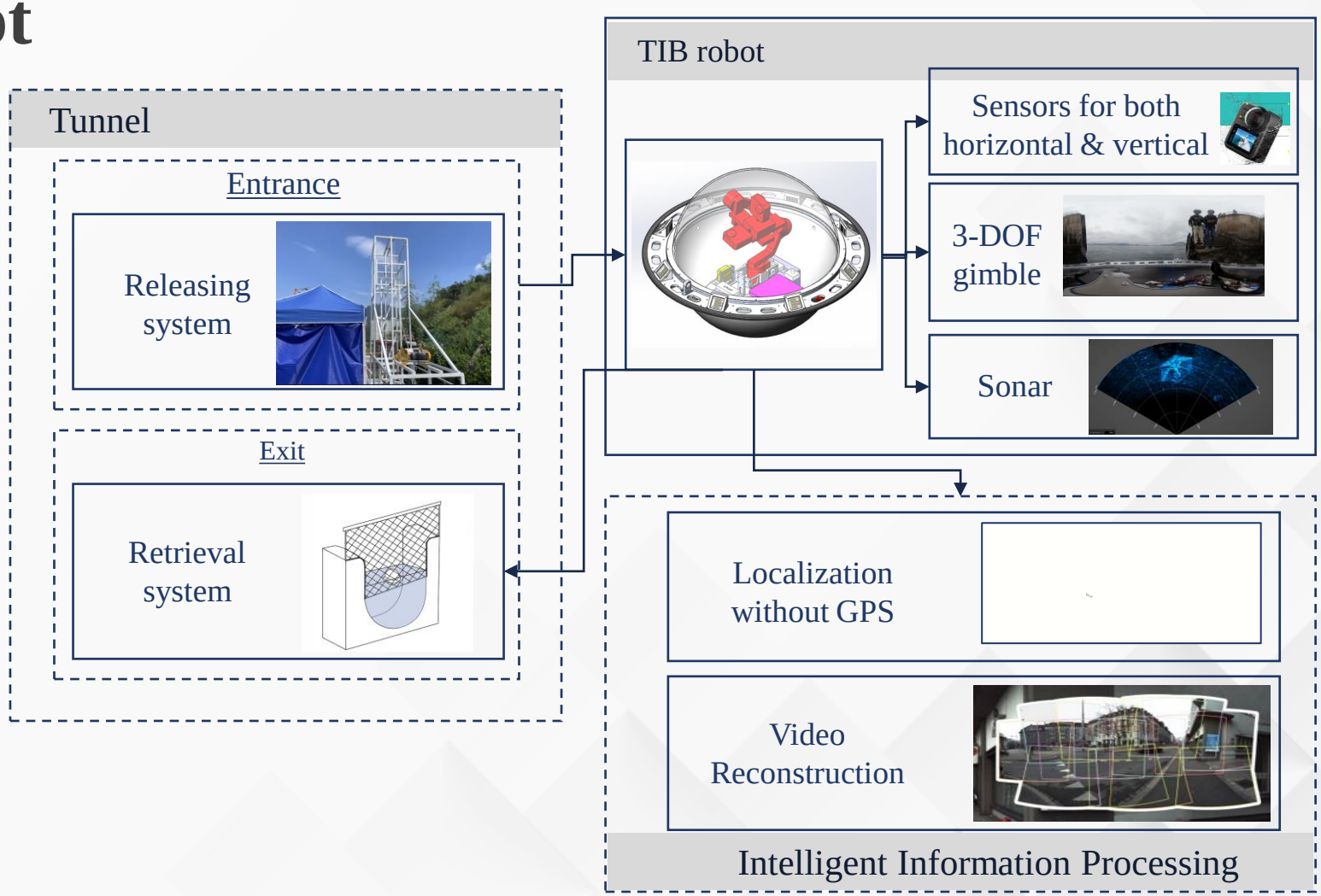


Intelligent Information Processing Platform

Tumbler Inspection Ball (TIB) robot.

TIB Robot

System Design



» TIB Robot – Stabilizing System

Motivation

Turbulent robot motion

Collisions within the tunnel

↓

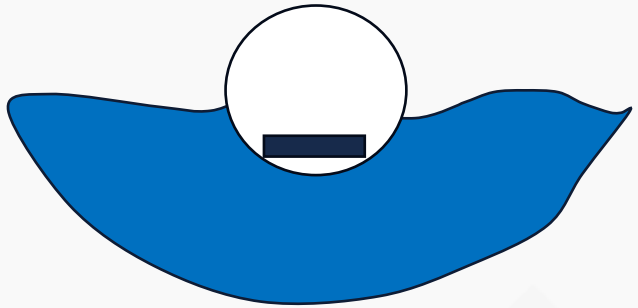
360-degree video shaking and blurring

↓

Degenerate inspection performance

Solution

Self-stabilizing Tumbler inspection ball



Intrinsic stability and collision protection

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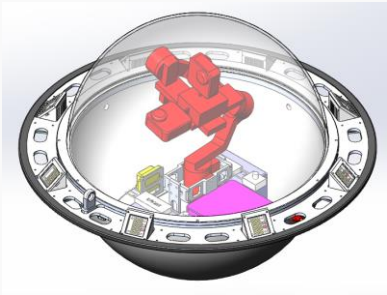
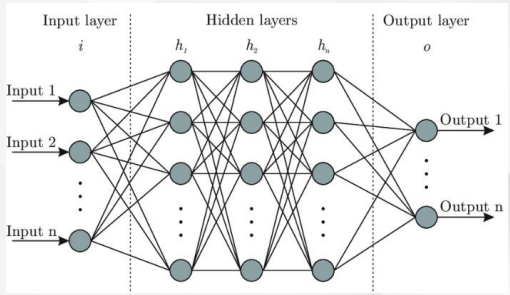
Gimbal Compensation



Gimbal automatic control detects and compensates for the camera movement

+

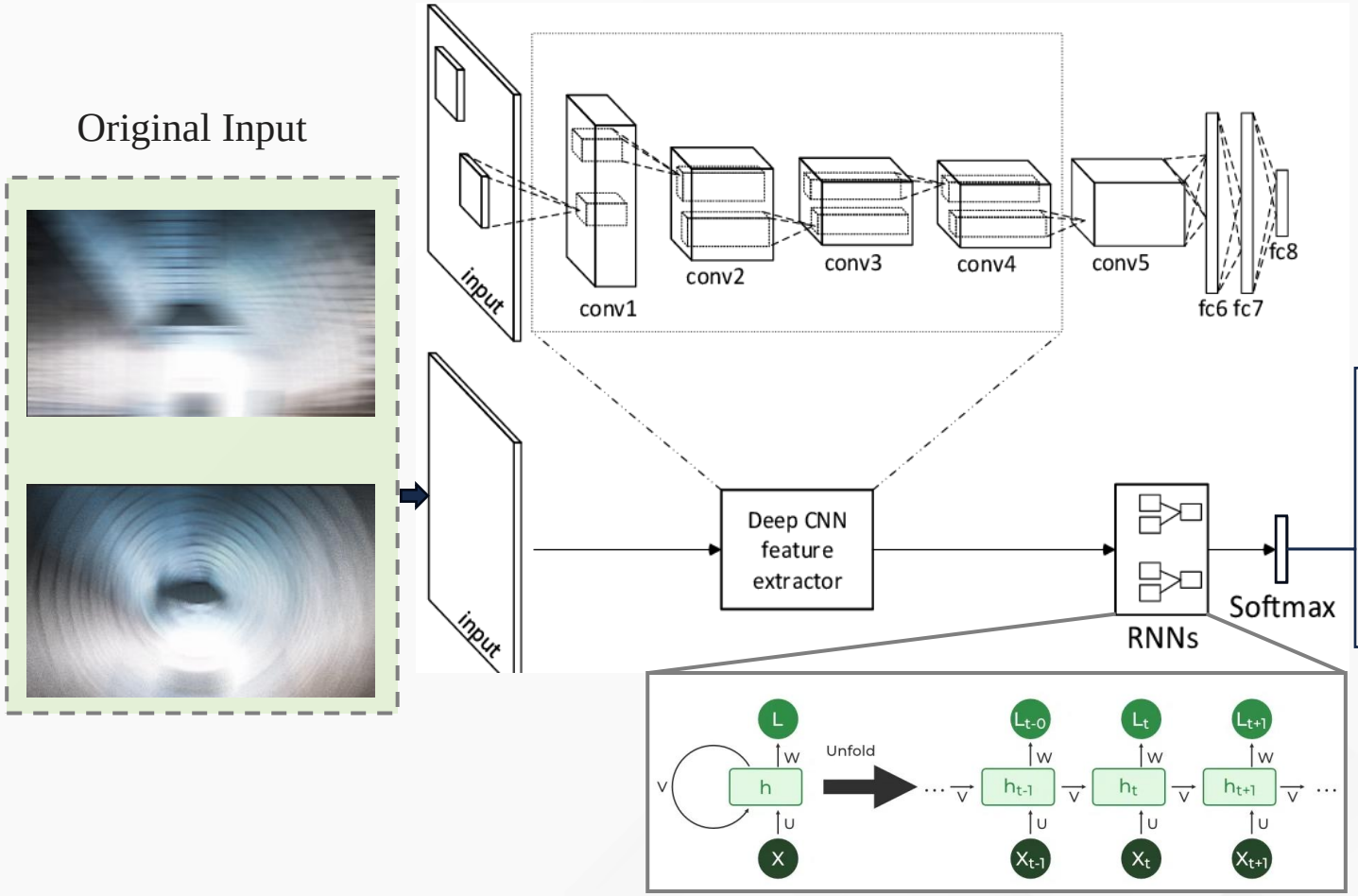
Image Processing Algorithm



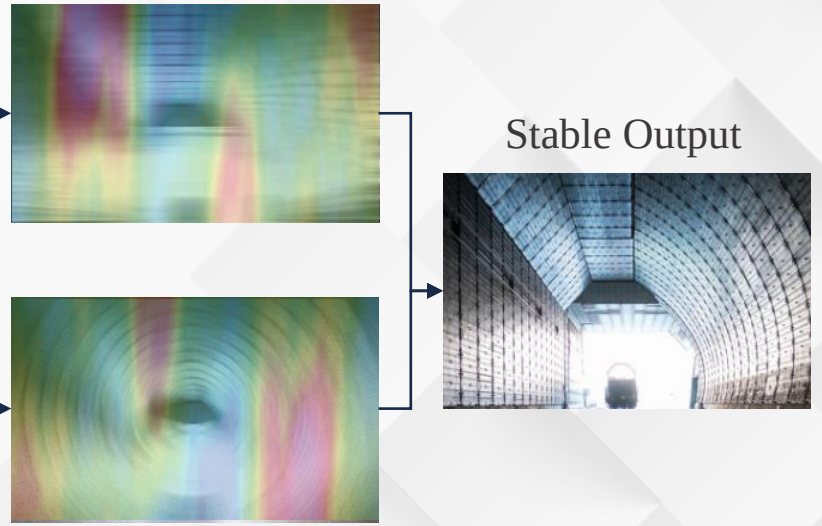
AI-based stabilizing algorithm analyzes and compensates the vibration of the obtained video

* https://www.researchgate.net/figure/Artificial-neural-network-architecture-ANN-i-h-1-h-2-h-n-o_fig1_321259051

» Stabilizing System – Video Data Processing



- Noise reduction
- Vibration compensation
- Image blur removing



AI-based video stabilizing algorithm

Stabilizing System – Video Data Processing

Verification of video stabilizing algorithm

Original video

Stabilized video

Results

The stabilizing algorithm can effectively reduce the video vibration

Experimental Results

TIB Robot

Tunnel Environmental Challenges

- Water velocity
- Water wave height
- Temperature
- Pipe wall shape
- Pipe wall surface

Robot Performance Challenges:

- Stability
- Waterproof
- Sensing system
- Temperature and humidity
- IMU data

Front view

360º view

» Experimental Results

Remote Inspection

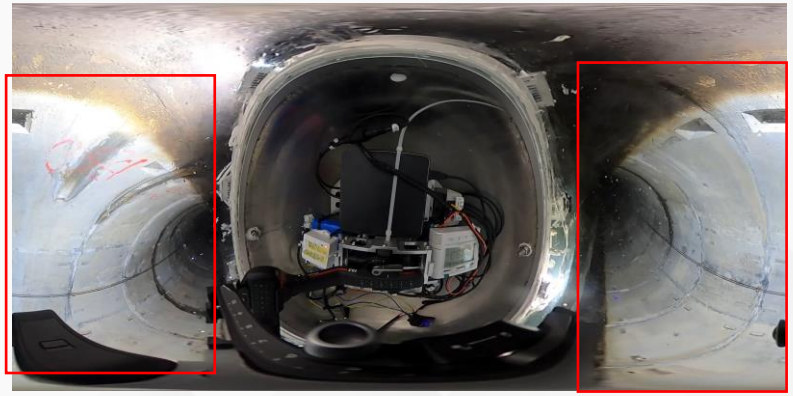
- ✓ Enhance inspection flexibility
- ✓ Allow 360-degree view
- ✓ Enable focus area inspection

Experimental Results

Site Experiments

- High-quality sensing system
- Effective stabilizing system
- Robot's CoG and waterline design

Pipe wall details



Stabilized image (video)

5cm from water surface

TIB Robot: Summary

INNOVATION
- Tumbler robot for watered tunnel
- Triple vibration reductions

SAFETY
- Enable inspector remote inspection
- Confined space inspection improvement

DATA
- Better data collection
- Enable underground data transmission

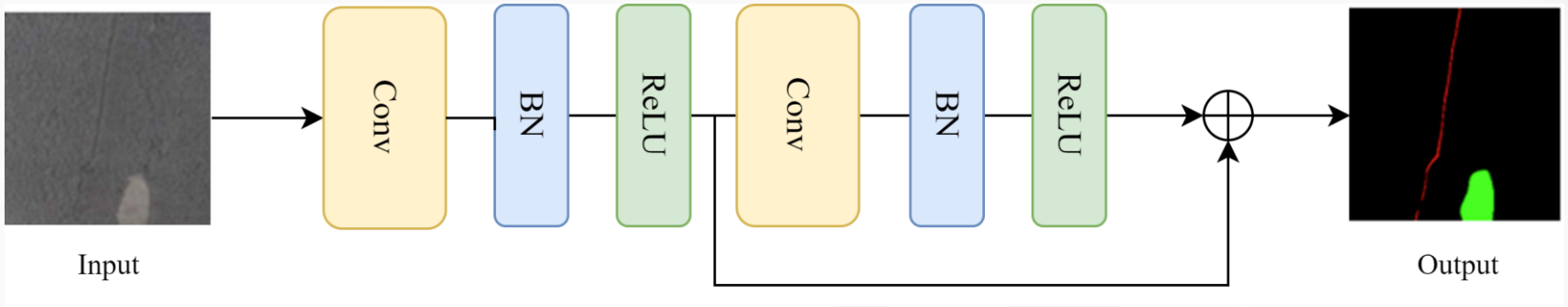
SAVING
- Planning and execution time
- Inspection duration
- Labour



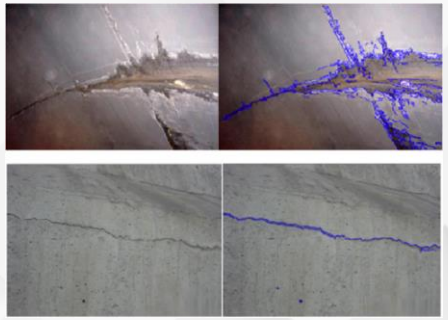
Further Research Work

AI-based inspection algorithm for THEES

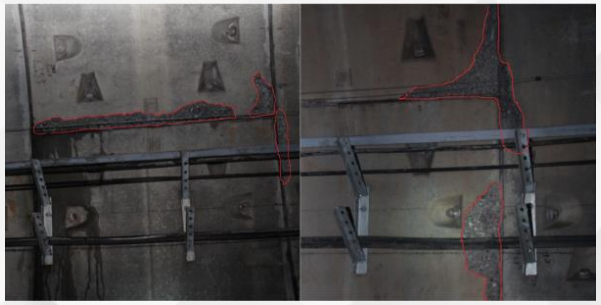
Real-time concrete crack and spalling detection for tunnel inspection based on AI.



Concrete detection nerual network



Intelligent crack detection

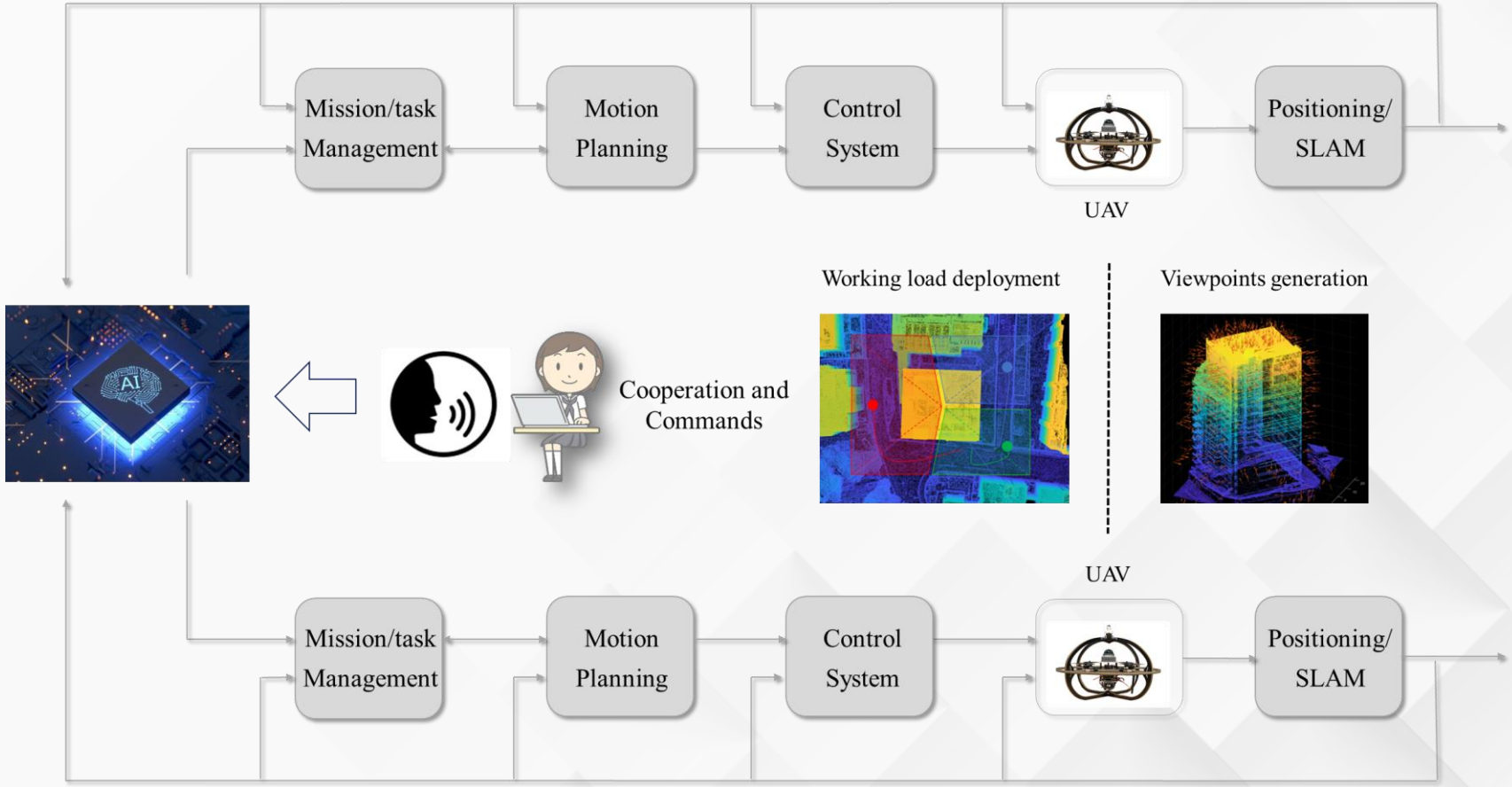


Intelligent spalling detection

Huang, Z., Fu, H., Chen, W., Zhang, J., & Huang, H. (2018). Damage detection and quantitative analysis of shield tunnel structure. *Automation in Construction*, *94*, 303-316.

UAV-based Autonomous Outdoor and Indoor Inspection

A Multi-Drone Based Autonomous Outdoor Inspection System



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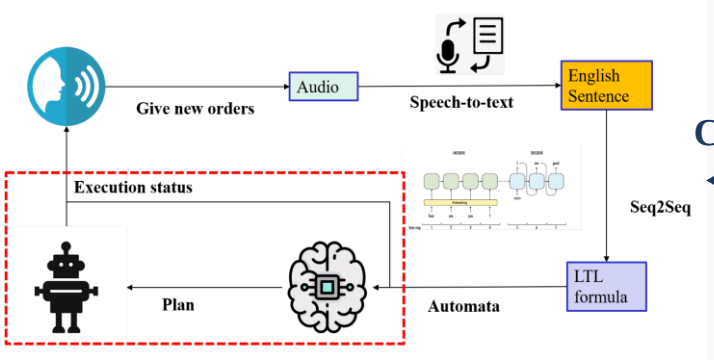
Autonomous Inspection in Indoor Confined Space

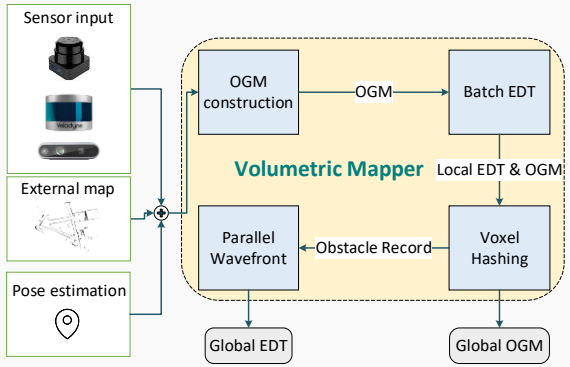
GPU-accelerated mapping algorithm for exploring unknown GPS-denied environment



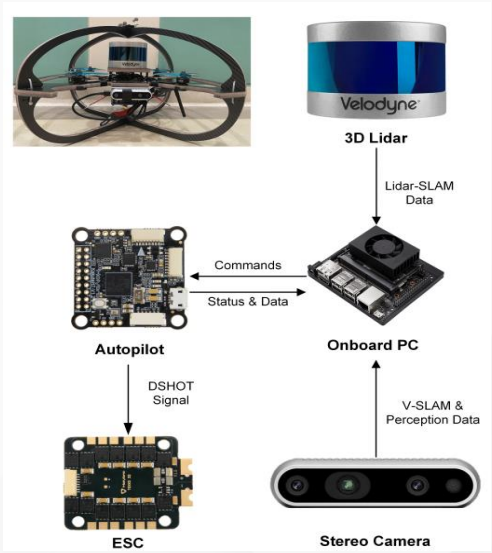
User-friendly interface for human-in-the-loop high-level tasking

Commander

Status



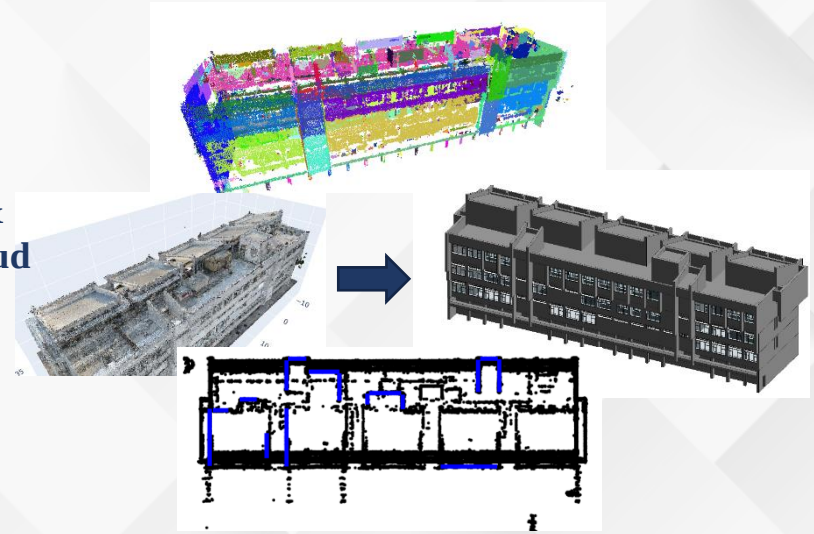
Onboard Navigation



Hardware Platform
(Environment Perception)

Image & Point Cloud

Automated point clouds to BIM process



Building Information Modeling System
(**Data Management and Modeling**)

Collision-resilient drone design and collision-inclusive motion planning

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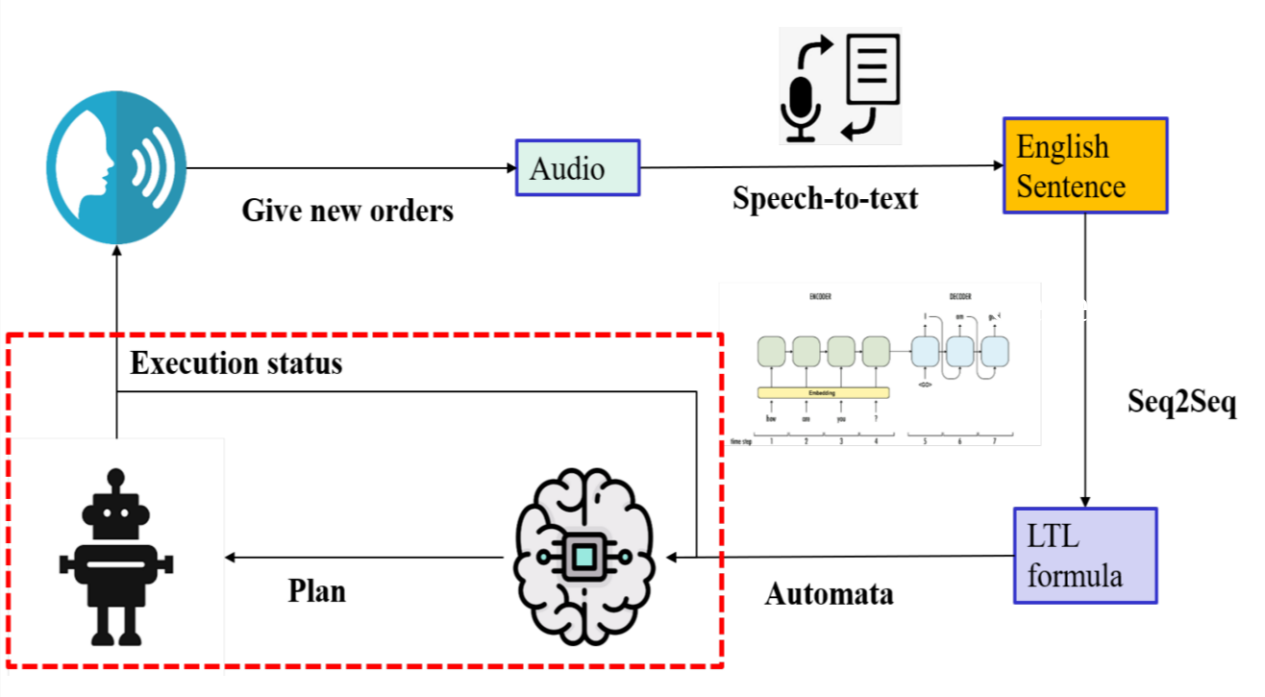
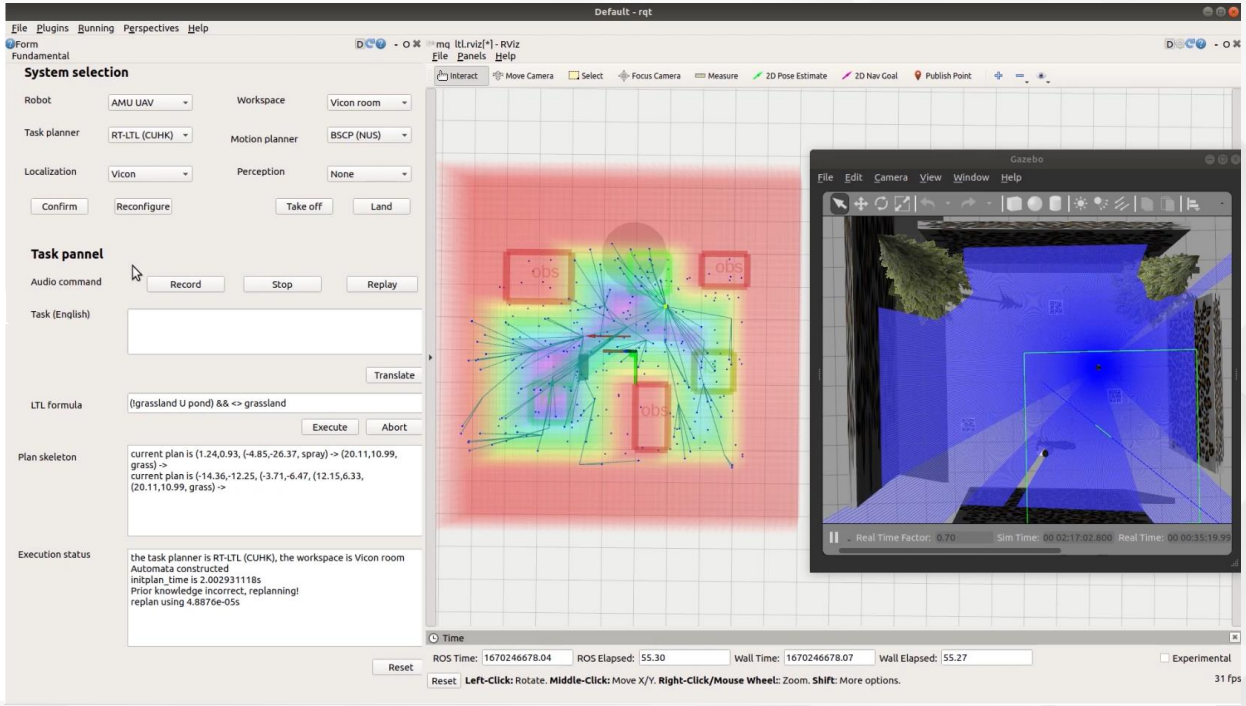
» Task Management System





No. 63/450,314 – A human-in-the-loop system for mobile robot task planning (Patent application in progress)

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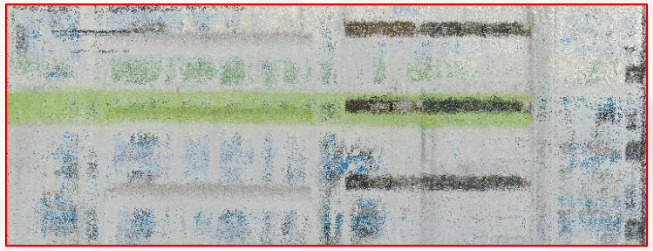
3D Digital MODEL Construction

Others



(6 h 39 mins, 65.8 Million Points)

HKCLR

Our solution: (35 mins, 305.8 Million Points)
(11.4 times faster, 6 times more accurate and complete)

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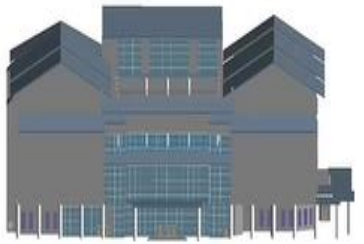
Indoor large-space inspection

Client: Government, Property Manager/Developer

Multi-drone based outdoor inspection

Application Cases

Heritage building conservation



Scan to BIM

Social Impacts

Enhanced Safety, Reduction in Human Risk , and Reliability of Sewage Treatment

Environmental Protection

Economic Efficiency

Potential for Broader Application

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THANKS FOR YOUR ATTENTION

THANKS to DSD'S SUPPORT AND COOPERATION