The Implementation of Unmanned Autonomous Systems for Railway Inspection

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Monash Institute of Railway Technology (IRT)

- Monash University is the largest university in Australia and ranked in the top 1% of Universities internationally
- Monash is ranked #1 in Australia for engineering and technology
- One of the key research and technology capabilities is the Monash Institute of Railway Technology (IRT)
- Centre for World University Rankings CWUR identified Monash Transportation Research as No. 1
IRT Historical Timeline

1972
Railway Research activities commenced at IRT's predecessor SHP's Melbourne Research Laboratories (MRL)

2000
Established IRT at Monash University

2002
Engineers Australia's Railway Technical Society of Australasia (RTSA) Rail Engineering Industry Award for Excellence in Railway Research

2002
Implementation of first heavy haul autonomous Instrumented Revenue Vehicle (IRV)

2010/11
Rio Tinto commissioned state of the art IRTV Technology throughout its fleet

2012
Celebrated 40 Years of Excellence in Railway Research

2015
BHERI Best Research & Development Collaboration Award

2016
IRT was identified as the Premier Track and Vehicle Research Centre in Australia

2013
One of the most successful business units at Monash University, generating highest industry funded research income

2014
Australian Academy of Technological Sciences and Engineering (ATSE) Clunes Ross Award for IRT senior staff
IRT’s Enterprise Partnership

- Established significant technical partnerships within the railway industry
- Provides technical assistance to the world’s benchmark heavy haul railway operations
- Assisted more than 160 other railway entities, including MTR Corporation in Hong Kong and Singapore MRT
- Completed over 500 projects with significant tangible benefits
# Global Partnerships and Networks

## International Network

<table>
<thead>
<tr>
<th>Organization</th>
<th>Partner</th>
</tr>
</thead>
<tbody>
<tr>
<td>UN Economic and Social Commission for Asia and the Pacific</td>
<td>Thailand Institute of Scientific and Technological Research</td>
</tr>
<tr>
<td>Asia Development Bank</td>
<td>Universitas Gadjah Mada, Indonesia</td>
</tr>
<tr>
<td>International Union of Railways</td>
<td>University of Pretoria, South Africa</td>
</tr>
<tr>
<td>Indian Institute of Technology Bombay, India</td>
<td>Chalmers Railway Mechanics, Sweden</td>
</tr>
<tr>
<td>Southwest Jiaotong University, China</td>
<td>Hong Kong Polytechnic University</td>
</tr>
<tr>
<td>Bryansk State Technical University, Russia</td>
<td>National Research Council, Canada</td>
</tr>
<tr>
<td>Institut Teknologi Sepuluh Nopember, Indonesia</td>
<td>Transport Technology Centre, USA</td>
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## National Network

<table>
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<th>Partner</th>
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<tbody>
<tr>
<td>Australasian Railway Association</td>
<td>CSIRO</td>
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<tr>
<td>Railway Technical Society of Australia</td>
<td>Australasian Centre for Rail Innovation</td>
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<tr>
<td>Rail Industry Safety and Standards Board</td>
<td>Rail Manufacturing CRC</td>
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<tr>
<td>Standards Australia</td>
<td>University of Wollongong</td>
</tr>
<tr>
<td>Australian Transport Safety Bureau</td>
<td>Central Queensland University</td>
</tr>
<tr>
<td>Rail Track Association Australia</td>
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Monash IRT Snapshot

47 years of railway innovation starting at BHP

19 years as part of Monash University

160+ partners

500+ projects Since 2000

83+ engineers, scientists, technicians and research associates

World first technologies
- Asymmetric wheel-rail profiles
- Instrumented Ore Car
- Phased array

National and international recognition for staff and projects
Railway Operations and Maintenance

- Management of Risk
- Improve Safety
- Maximise Throughput
- System Performance

Minimise Track Possession
Minimise Survey Response Times
Minimise Staff Time On Track
Current Challenges - Remote and Significant Quantity of Infrastructure

- Railway operators face several challenges related to monitoring and maintenance of infrastructure
Confined or Inaccessible Structures
Automated Condition Monitoring of Railway System

- Autonomous structural health condition monitoring system on revenue service rollingstock (during normal operation)

- Over 85 IRT instrumented vehicles have been installed

- Supports an expanding network of railway and provides
  - Near real time reporting of the condition of the track and operations
  - Effectiveness of maintenance activities
  - Evidence based maintenance planning
### Instrumented Revenue Vehicle – System Approach

<table>
<thead>
<tr>
<th>Monitored Parameters</th>
<th>Passenger/Freight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Peak Accelerations</td>
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<tr>
<td></td>
<td>- Ride Index (Based On RISSB AS-7513.3-2014)</td>
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<tr>
<td></td>
<td>- Ride Comfort (Based on ISSO 2631.1.216)</td>
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<tr>
<td></td>
<td>- Ride Safety based on acceleration Jerk (g/s)</td>
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<tr>
<td></td>
<td>Wagon Stability</td>
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<tr>
<td></td>
<td>- Roll, Yaw and Pitch</td>
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<tr>
<td></td>
<td>- Detection of vehicle instability</td>
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<tr>
<td>Bogie Stability</td>
<td>- Primary Spring Displacements and Bogie Vibration Modes</td>
</tr>
<tr>
<td></td>
<td>- Hunting Detection</td>
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<tr>
<td></td>
<td>- Spring Binding Detection</td>
</tr>
<tr>
<td>Geometry</td>
<td>- Rail Vertical Profile</td>
</tr>
<tr>
<td></td>
<td>- Rail Twist</td>
</tr>
<tr>
<td></td>
<td>- Curvature</td>
</tr>
<tr>
<td>Running Surface</td>
<td>- Discrete defects</td>
</tr>
<tr>
<td></td>
<td>- Corrugation</td>
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</tbody>
</table>
Automated Measurement, Processing & Reporting

Continuous Data Collection During Traffic Hours

Automated Tracking During Normal Operation

Automated Data Processing

Flexible Customized Reporting

In-Train Forces and Acceleration

Track Responses and Condition

Near Time Reporting

Integrate Reports with Internal Systems

System Performance & Maintenance Planning

Emergency Response

Trends
Correlating Passenger Comfort, Vehicle Performance and Track Condition

- Track Geometry defect leading to high lateral jerk
- High lateral jerk
- Cross Level Defect
- Out of phase left/right vertical rail profiles
Overall Maintenance Effectiveness

Maintenance records represented by black lines – in this case, grinding maintenance has improved rail running surface.

Maintenance records represented by black lines – in this case, tamping maintenance has improved track geometry condition.
Detection of Weld Condition

- Rail profiles can be sampled to 5mm increments along the track
- Running surface information can be extracted
- Dipped and peaked welds can be identified as well as pumping
Virtual Track Inspection

- Immersive Visualization Platform
Virtual Track Inspection
Wayside Autonomous UAVs

Skysense

Airobotics

H3 Dynamics
Bad Weather, Derailment & Disasters Inspection

- Quick, efficient but thorough surveying is key
- Surveys are often conducted under less than ideal conditions
  - Flooding and Slips
  - Derailments
  - Night Surveys (To prevent disruption)
  - Extreme Heat
Unmanned Autonomous Systems (UAS)

- Rapid deployment times
- Reliable and simple
- Staff out of the danger zone
- Large areas covered quickly
- Value from drones and data analytics
- Timestamped data collection including imagery
- Digital reconstruction of key assets
Complete the Data Workflow for Railway Inspection and Operation
UAS Platform Types

- QuadPlane
- Hover
- Long Endurance
- Payload Capacity
- Multirotor
- Plane
Potential Applications of UAS
Monash IRT UAS Hardware Research

- Tunnel & Culvert Inspection
  - Semi Autonomous Quadcopter Platform
  - Self Centring
  - LiDAR Scanner

- Rail Inspection
  - Rail Head Profiles
Set-point Tracking

Lower Corner

Upper Corner
Tracking Performance

- Proportional Integral Derivative (PID) controller is a control loop feedback mechanism widely used in industrial control systems requiring continuously modulated control.

- Integral Back Stepping (IBS) controller is a nonlinear controller Monash has designed to control the drone.
Circular Trajectory Tracking with Induced Disturbances

±5° pitch oscillation @ 1Hz

z-axis tracking error

PID

IBS

y-axis tracking error

PID

IBS
Infrastructure Inspection

360° camera for visual inspection

3D point cloud reconstruction

Crack line
Feature classification includes:

- Rail heads
- Track centreline
- Vegetation
- Ballast
- Overhead Wire
- Track Infrastructure
- Custom object tracking/detection
Virtual Track Condition Inspection
Static Track Gauge Measurement & Check

Broad Gauge Track (1600mm)
LiDAR – Tunnel Entrance

Yarra Valley Railway Tunnel
- 150m long
- Profile interval of 30mm @ 20km/h
- ~6,000 points/m² @ 20km/h
- Point cloud of ~20,000,000 points

Information
- ~1 million points per second
- 5mm accuracy
- High precision dual GNSS (with base station corrections)
- 400Hz MEMS IMU (for trajectory logging)
LiDAR – Tunnel Track Definition

Point cloud displayed by intensity value
LiDAR – Tunnel Definition
LiDAR – Analysis

- Encroachment Analysis
- Maximum Structure Gauge Envelope
- Static & Kinematic Envelope Minimum Clearance
- Platform Height and Offsets
- Ballast Profiling
- Overhead Wire Height and Stagger
- Track Geometry Measurements
Tunnel Inspection

Red indicates the tunnel is bulging inwards slightly.

Blue indicates the tunnel is bulging outwards slightly.
UAS Survey

- UAS survey produces GBs of imagery
- This information is converted into
  - 3D Models
  - High Resolution Maps
  - Elevation Maps
  - Time-Series Comparisons
3D Point Clouds and LiDAR Models

- Point clouds allow for accurate structure representation
- Producing digital twins of infrastructure
Heavy Haul Project

- Heavy haul operator in Pilbara engaged IRT to survey several cuttings that were hazardous to access by foot
- Survey was completed within an hour
- Revenue service was never stopped
- Digital twins of the rail and surrounding infrastructures were completed within days
Photogrammetry and Digital Models

- Georeferenced 3D model to scale
- Accuracy from 0.05 to 0.2m
- Review access roads & stockpiles
- Investigation of
  - Cross-sections
  - Volume measurements
  - Flood/ground water studies
  - Snapshot of asset condition
  - Review access roads & stockpiles
Digital Elevation Models

- Elevation Maps Referenced with GPS
- Quantification of
  - Global Track Alignment vs Design
  - Ballast shift
  - Erosion
  - Flood Susceptibility
  - Access Road Visibility
Comparisons Over Time

- Perform multiple surveys at a single site
- Changes can be identified visually in 3D models
- Degradation and the rate of degradation can be quantified
- Preventative maintenance can be planned
- Foliage growth can be quantified using UAS surveying
Orthophotos

Google Earth

Map Generated from UAS Survey
Two IRT papers were awarded best papers (out of 9 categories) at the 2019 International Heavy Haul Conference in Narvik, Norway (10-15 June 2019)

More than 130 papers were presented and 500 railway professionals attended from 37 countries

Monash Institute of Railway Technology was the only organisation to receive 2 best paper award
Photogrammetry – Railway Infrastructure Inspection
Rail Head Inspection
Rail Head Condition and Profile Inspection

UAV Images

Profile Comparison

3D Reconstruction

Textured Mesh

Red: reconstruction result; Blue: 60kg rail; ICP result

Total elapsed time: 0.014 s
Regulatory Framework for use of UAV in Railways

- United Nations Economic and Social Commission for Asia and the Pacific (UN ESCAP) and Monash Institute of Railway Technology (Monash IRT)
- Researching the unique challenges associated with the use of Unmanned Autonomous Vehicles (UAVs) in and around operational railways for the monitoring and maintenance of railway infrastructure
- Research involves knowledge capturing of experiences and concerns of rail operators and others working in the railway environment in relation to deployment of UAVs
- Outcome of the research has articulated the safety requirements for UAVs to operate safely at rail sites and current regulation and procedures in place that govern the use of UAVs