An Application of Autonomous Vehicles to Manage High-Risk Exposure in Geothermal Operations

Hannah Martin[1], Ben Gibson[1], Emily Collis[1], Steven Gray[1], Craig Martin-Smith[2] and Johan Potgieter[2]

[1]Mercury, Rotokawa Power Station, 162 Rapids Road, RD2, Taupō, 3378, New Zealand

[2] Wrybill Robotics, 11 Dairy Farm Road, Palmerston North, 4472, New Zealand

emily.collis@mercury.co.nz

ABSTRACT

As part of an effort to keep people safe, Mercury is developing an autonomous inspection vehicle (AIV) as a proof-of-concept project alongside New Zealand company Wrybill Robotics. The aim is to reduce personnel exposure to high-hazard environments on geothermal and hydro power generation sites. The initiative leverages autonomous robotics, thermal imaging, hydrocarbon (pentane) cameras and post-image analysis to allow comprehensive monitoring of site environments.

The primary objective of this project was to minimise human exposure to hazardous areas on site, by using a remote autonomous inspection vehicle that allows for safer monitoring of plant. In addition to scheduled inspections, the autonomous vehicle will be deployable in emergency scenarios which will allow operators to assess the plant and make decisions from a safe area.

Another key objective was the successful execution of reliability trial runs on Mercury's Rotokawa site. These trials tested the autonomous vehicles navigation system and provided photo and video data for analysis. Results from these trials will guide further technology enhancements and validate the autonomous vehicle's reliability and readiness for regular full-site routes.

Following the Rotokawa site deployment, the project is proposed to expand to Mercury hydro generation site Ohakurī by trialling two indoor autonomous vehicles using a different navigation technology. This aligns with Mercury's strategy to use digital solutions to reduce risk to their people.

This initiative aims to show the potential of using autonomous systems to transform how power generation sites are monitored, and risk is managed.

1. INTRODUCTION

1.1 Background and Objective

Mercury and the geothermal industry have hazardous facilities that often require human intervention for monitoring and failure investigation. This has the potential for human exposure to dangerous environments. Within an Industry 4.0 workstream, Mercury has a goal of leveraging technology to make work safer for their people.

The aim of this project was to begin a phased proof-of-concept project that began with utilising roaming autonomous vehicles to obtain photo and video data over a set route repeated multiple times per day. This phase included two iterations of the AIV where learnings were applied ensure continuous improvement. The initial AIV was implemented in a small scale, with monitored routine routes applied, whereas the second iteration introduced full autonomous inspections in a full-inspection route.

Mercury is planning an additional phase that will utilise the resulting data to analyse plant changes remotely and to check plant alarms from a safe environment, ultimately integration into existing station monitoring and asset management systems.

2. INITIAL TRIAL PERIOD – M1

The first iteration autonomous inspection vehicle (known as M1) shown in Figure 1, was designed and built by Wrybill Robotics based in Palmerston North, New Zealand. The first use of M1 was at Mercury's Rotokawa site. M1 undertook a small, repeated route to test the reliability of the autonomous function. It was important to check the vehicle would reliably stay on its autonomous path due to presence of pentane at Rotokawa, and when objects were detected, it would avoid collision by stopping.

Figure 1: Autonomous Inspection Vehicle at Mercury's Rotokawa Geothermal Site

2.1 Autonomous Route

The outdoor AIV uses Fixed Waypoint Navigation to follow its route. At Rotokawa, the AIV follows a pre-recorded GPS coordinate sequence to follow a pre-determined inspection route. Waypoints, shown in Figure 2, define straight-line segments to ensure repeatability. The way this path is planned ensures exact repetition of the same path on each mission and

Proceedings 47th New Zealand Geothermal Workshop
11 -13 November 2025
Rotorua, New Zealand
ISSN 2703-4275

low computational overhead as no dynamic planning is required. However, this method has limited flexibility as it cannot adapt to unexpected obstacles without manual route updates.

Real-Time Kinematic (RTK) GPS is relied on for navigation at a centimetre-level accuracy. By comparing carrier-phase measurements from two antennas spaced at a fixed baseline, it calculates accurate latitude, longitude and heading in real time.

Light Detection and Ranging (LiDAR) is used to assist with collision avoidance/object detection and on entry and exit to the charging box.

Figure 2: Autonomous Inspection Vehicle Route at Rotokawa Site Showing Stops Where Photos Are Taken

2.2 Risk Analysis

Before M1 was delivered to site, it was important to identify potential risks. This allowed for each risk to be mitigated. The risks identified are details in the following sections.

2.2.1 Fire and Pentane Ignition

Thermal runaway could lead to the AIV catching fire. If this was to occur, it could ignite pentane due to fire on a nearby unit.

To mitigate this risk the AIV has sealed lead acid batteries located in a sealed housing. This mitigates ignition risk, and geofencing was employed to keep the AIV out of chained off hazardous areas where risk of pentane ignition is higher.

2.2.2 Unauthorised Access to Hazardous Areas

M1 used GPS to follow a predetermined autonomous route, so if GPS was lost there was risk of the AIV entering hazardous areas.

Geofencing prevents the AIV entering hazardous areas. If GPS is lost and the robot loses geo-location, it would stop at its current location until re-establishing geo-location or notify an operator by email so they could intervene by manually driving to the home charge box.

2.2.3 Collision with Plant or Personnel

There is a risk of collision with either plant, equipment or personnel.

The AIV has object detection cameras to avoid collision with any objects. These cameras have a “slow-down” polygon programmed of 2 m from the centre of the AIV and a stop polygon 1.5m from the centre of the AIV, to avoid collision.

2.2.3 Network Connection Lost

If the AIV loses network connection, it would disable the ability to manually control the AIV and would mean a loss of live data.

If network connection fails then the AIV has been programmed to either return home if GPS is active, or an emergency stop (e-stop) is in place if GPS is also lost.

2.2.3 Major Incident

If a major incident (i.e. a pentane leak or fire) occurred at Rotokawa leading to a site evacuation but the AIV is active in the field, there is a risk that it could lead to ignition and cause pentane fire.

This risk is mitigated by not allowing the AIV to enter the hazardous areas under the current proof-of-concept. Future iterations may look to enable the AIV to enter the hazardous areas for more thorough inspection, in which case there would be measures in place to ensure the AIV would stop or evacuate when site was evacuated.

2.3 Learnings from M1 Trial

Learnings from the M1 initial trial are as detailed below.

- The brake release did not work after the e-stop had been activated. This meant that the AIV was unable to be manually pushed out of the way, causing a potential hazard. Wrybill Robotics corrected this by switching the link between the e-stop and brake switch. This meant that the e-stop is activated when the brake switch is activated (in case the e-stop is not activated first).
- The AIV lost GPS when trying to dock in its charging box, causing it to often miss the charging plates and not charge. This caused delays for the next rounds due to low battery. Initially, a mechanical remedy was put in place by means of guide plates to assist the AIV into the correct position.
- The AIV autonomous route was too slow during planned rounds, moving slower than walking speeds. This meant that there was a potential for the AIV to become a hazard for other vehicles on site. As a result, the AIV speed was increased to approximately 0.67 m/s (2.4 km/h), so it could move twice as fast.
- The AIV repeatedly lost GPS at the start of autonomous routes, and occasionally at the end of a round before docking. This caused routes to be incomplete and docking to be difficult. Both issues lead to manual operator intervention. A recommended resolution for this was to install LiDAR.
- An overcurrent issue occurred on the battery charger, causing the AIV to come out of the charging box and stop. This was due to atmosphere on site oxidising the brass charge plates on the AIV and charger prongs. The corrosion increased the resistance through the plates

ISSN 2703-4275

causing a voltage drop from the charger to the AIV. This issue is solved by regularly removing the oxidation monthly. Future plans include changing to contactless charging.

- Sunstrike became an issue due to the timing of the routes, combined with the location of the sun. In the first iteration of AIV stereo cameras were being used for object detection. These cameras are susceptible to lighting level extremes in an environment – if it is too dark or too bright, it cannot see. LiDAR was installed for object detection going forward as lighting levels and changes have no effect on the sensors.
- The AIV object detection was being activated by fins on radiators on site – as with the sun strike. This was also solved by the installation of LiDAR.
- A major learning came from a near miss collision of the AIV and a flat deck truck. A flat deck truck was parked near the AIV programmed autonomous route. The flat deck of the truck was hanging over the route but was not identified as an object due to it being too high for the 2D LiDAR to detect (with only a 2D plane of view). The PTZ (Pan, Tilt, Zoom) camera on the AIV would have contacted the deck of the truck, and may have caused damage to the AIV itself or the truck but on this occasion was stopped manually by a Wrybill Robotics employee who happened to be watching the camera footage. As a result, 3D LiDAR was installed to enable object detection above and below the 2D line of detection.
- During the reliability testing of the route, the AIV was taking photos at ten predetermined stops to ensure repeatability of photography. There were some discrepancies in the photos, so Wrybill Robotics changed the settings to take the photos from a wider angle at higher resolution and digitally zoom to the asset in the photo. This reduced the discrepancies while maintaining resolution of the image. Examples of images are shown in Figure 3 and Figure 4

Figure 3: Repeat Photography Example - 18-06-2025

Figure 4: Repeat Photography Example - 25-06-2025

3. UPDATED AUTONOMOUS INSPECTION VEHICLE – M2

A second autonomous inspection vehicle chassis (M2) was assembled, implementing the learnings from M1. Once on-site at Rotokawa and approved for autonomous route, Wrybill Robotics programmed a full site route including approximately 60 photo stops.

Due to the longer route, the battery life for M2 was improved to twice that of M1. This allowed enough battery life to make the full route three times a day with charges in between.

When testing M2 object detection it was noted that the AIV stayed at full moving speed until it was within 100-150 mm of the object (in the testing case, a human). To reduce risk Wrybill Robotics changed the coding to allow for a longer "slow down" period before the AIV stopped completely.

More learnings came with the second iteration AIV:

- The autonomous route required adjustment to ensure it stayed in straight lines on the left-hand side of the road as much as possible.
- The AIV has four wheels and uses skid steering. When a full site route was tested, it was discovered this way of driving causing damage to the ground when it turned. To remedy this, Wrybill Robotics has programmed the AIV to reverse out of areas rather than turning and driving forwards. This required 3D LiDAR to be installed on both sides of the AIV to allow for driving in both directions. At the entry and exit of the charging box, a concrete pad was laid to ensure the necessary turning at this point of the route did not dig up the ground further.
- Unforeseen issues such as daylight savings and dirty camera lens' also caused issues but were remedied by software updates and monthly serving respectively
- For maintenance to occur, the AIV needed to be manually moved out of its charging box rather than triggering a full route. This function was also added with the M2 iteration of the vehicle.

4. FUTURE OPPORTUNITIES

4.1 Analysis of Captured Data

When data from the photo and video pick up on autonomous routes is reliably being captured, the scope includes analysing this data to provide insights into plant changes. There are multiple options for this analysis:

Proceedings 47th New Zealand Geothermal Workshop
11 -13 November 2025
Rotorua, New Zealand
ISSN 2703-4275

- A program provided by Wrybill Robotics that uses artificial intelligence (AI) to detect changes, this is in a beta trial.
- Using Mercury's Computerised Maintenance Management System (CMMS) add in. This also uses AI to analyse images for defects and anomalies.

Both options would require training the AI models to analyse images for specific tasks, for example in this case oil leaks or changes in gauges. The objective is to be connected with Mercury's CMMS to enable auto-generation of work orders that provide early intervention opportunities.

4.2 Roll Out of Outdoor Autonomous Inspection Vehicle to Other Sites

After M2 trial, M1 will be upgraded with 3D LiDAR, improved battery life and charging box upgrades. The code will be changed to allow the AIV to drive backward as well as forward. Thermal and pentane cameras will be added to allow for thermal analysis and pentane detection to allow for faster detection of overheating issues or pentane leaks on site.

4.3 Roll Out of Indoor Autonomous Inspection Vehicle to Ohakurī

Once Wi-Fi and access points are confirmed, indoor autonomous inspection vehicles (Figure 5) will be implemented at Mercury's Ohakurī hydro station on the Waikato River.

The indoor AIV's use Simultaneous Localisation and Mapping (SLAM) with 3D LiDAR to localise against a pre-recorded map. Scan matching algorithms (e.g. Iterative Closest Point) align live point clouds with the recorded map.

These AIV have infrastructure independence, so no reliance on GPS. The AIV has a function to assist with drift correction – the more the AIV completes its planned route, the more precise it will get about its position overtime due to building a more accurate map.

Figure 5: Indoor Autonomous Inspection Vehicle

Real-time SLAM also demands much greater computing resources for scan processing.

The indoor AIV platform computes its route at runtime using the SLAM-generated map. A global path planner calculates an efficient trajectory, which a local trajectory tracker refines continuously based on live sensor data.

This way of planning adapts to temporary obstructions and the map can be updated. In future, there is possibility to incorporate dynamic obstacles into the plan without human intervention.

For both indoor and outdoor AIV's, once a path is established, they both employ the same trajectory-following "regulated pure pursuit" controller – where the controller blindly finds a point along the path at a fixed distance (like a carrot on a stick), and the robot continuously turns towards that point (carrot) and "pursues" it.

Regulated pure pursuit is the technical name of the type of controller the AIV's use. As with pure pursuit, takes a path, calculates a point further along that path at a varying distance and directs the AIV to that point, but regulated pure pursuit takes the curvature of the path ahead into consideration (i.e. the "stick the carrot is hanging from" gets shorter when the path is curvy, so the AIV does not look too far ahead and skip too much of the path). A visual representation of this can be found in Figure 6.

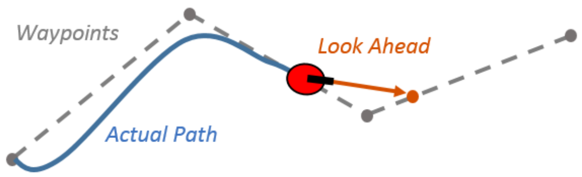

Figure 6: Visualisation of Regulated Pure Pursuit (MathWorks, n.d)

4.3 Manual Driving

Currently, Wrybill Robotics can manually drive the AIV to any position on site. In future there will be the capability for Mercury operators to manually drive the AIV outside of its autonomous route schedule to any of the waypoints or to monitor any plant that may have issues or for generating plant start up to monitor a piece of equipment.

5. BENEFITS

The implementation of autonomous inspection vehicles on power generation sites provides an opportunity to keep people safe by removing people from hazardous areas for daily inspections. Having a remote operation also enables issues to be inspected by the inspection vehicle before putting people in danger.

The regular repeated route and associated photography provides regular and consistent inspection, compared to human inspection where smaller changes could be missed. This also creates the ability to see changes over time.

The ability to manually drive the AIV to monitor specific events such as Generation unit start up keeps people out of dangerous situations and allows them to be free for other tasks.

Pentane monitoring is currently undertaken monthly on site. With a pentane camera installed on the AIV monitoring will be undertaken daily, improving process safety. This will also assist in notifying of spot leaks that may have otherwise been missed.

With a central control room, some Mercury sites are remotely controlled. Having these AIV's on site improves visibility to the central operators over remotely controlled sites.

Longer term, this project has potential to lead to cost savings by improving maintenance strategies and reducing the number of forced outages.

5. CONCLUSION

The first iteration proof-of-concept project was successful in proving the hypothesis that an autonomous inspection vehicle was capable of roaming Mercury's Rotokawa site to take photo and video and assist in monitoring equipment and keeping people safe.

Future iterations of the autonomous inspection vehicle will include new technologies by way of thermal and pentane imaging and analysis of the images, as well as indoor proof-of-concept trials.

REFERENCES

MathWorks. (n.d.). *Pure pursuit controller*. *MATLAB & Simulink Documentation*. Retrieved June 13, 2025, from https://au.mathworks.com/help/nav/ug/pure-pursuit-controller.html