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Demonstration of an autonomous ultrasonic testing concept for rail flaws inspection

I. Durazo-Cardenas[1], A. Starr[1], W. Nofal[1], H. Liu[1], M. Rahimi[1], F. He[1], M. Poulter[2]

[1]Centre for Life-Cycle Engineering and Management
Cranfield University
Cranfield, United Kingdom
[2]Network Rail,
Milton Keynes, MK9 1EN
United Kingdom

Abstract

This research demonstrated the feasibility of autonomous ultrasonic inspections to technical readiness level (TRL) 5.

An autonomous prototype was constructed for this research, using both commercially available ultrasonics instrumentation, and an unmanned on-track vehicle platform, which comprised of a Clearpath’s Warthog and a road rail vehicle (RRV) trolley. During the test programme, the prototype was programmed to travel back and forth on a section of the test track.

Repeat fault inspections were successful in detecting seeded simulated defects, at depths of 23 and 27 mm. Detection was signalled by an audible alarm triggered by the ultrasound signals exceeding the flaw detector gate threshold. Fault detection message passing was also demonstrated using a simple plain text message over local area network (LAN) WIFI to a simulated server.

Consistency of the inspection prototype repetitive positioning was verified by odometry, global positioning system (GPS) and positional measurements, relative to the vehicle start and end positions to the fault. There was good agreement with the results of the three measurements methods. The positional error ranged from 3 to 7 cm.

This research highlighted the great potential for autonomous ultrasonic inspections. Limitations and future work recommendations are discussed.

Keywords: Autonomous, Robotics, Maintenance, Inspection

1 Introduction

Railway systems are key enablers of economic prosperity. In Great Britain, rail journeys have increased by 89% in the last 20 years, to reach a record 1.8 billion journeys in 2018-19 [1]. Clearly, routine rail inspection and maintenance work are vital to maintain these growing demands.

Ultrasonic railways testing (UT) uses a probe to send an ultrasound beam into a rail. The echo signals at an interface, such as the back of the object or an imperfection, are reflected to a transducer receiver. The reflection's intensity and arrival time are used to interpret the severity and depth. Network Rail's ultrasonic testing unit (UTU) fleet is one of the most successful plain line track ultrasonic inspections systems. Since deployment, regular line inspections have significantly reduced the number of annual rail breaks. However, pedestrian inspections are still required to manage localised defects and to confirm the criticality of indications found by the UTU. These inspections can be costly and labour intensive and inevitably have the safety issues concerned with pedestrian access to the track. An autonomous rail inspection and repair system (RIRS) can contribute to alleviate these issues [2].

Several studies have proposed the use of the autonomous unmanned aerial vehicle (UAV) and image recognition techniques to detect rail defects [3]– [8]. However, they have limited capability to detect subsurface defects. Other studies have proposed autonomous instrumented trolleys fitted with inspection capability [9], [10]. However, they were in the early stages of technology development.

The aim of this research is to demonstrate consistent fault inspection functionality on a section of test track. The objectives encompass the development and demonstration of a test prototype for autonomous ultrasonic testing. This research did not aim at developing new inspection and repair methods. Rather, it used both available of the shelf equipment/components and current autonomy research technology advancements.

The project scope boundaries were defined as follows:

In scope:

- To demonstrate inspections using an available autonomous vehicle and RRV conversion on plain test track.
- Simple ultrasonic identification of defects on plain line track.

Out of scope:

- The research programme focused on demonstrating autonomous inspection functionality, rather than the ultrasonic system inspection capability (already a mature system).
- The prototype conducted inspections and identified defects. It did not repair defects.
- Demonstrations were not conducted on S&Cs.
- The Warthog performed pre-defined inspection tasks, using seeded defects. Full autonomous defect search and inspection was out of scope.

2 Methods

An inspection prototype comprising a pedestrian ultrasonics inspection system, an autonomous, and a custom-made road rail vehicle (RRV) trolley was constructed, see Figure 1.

Figure 1. Inspection prototype

The RailScan 125 (Sonatest) is a system for pedestrian inspections. The probe frequency was 2.5 MHz, with adjustable beam inspection settings of 0, 70 and 0-70 degrees, using water as couplant. A bracket was used for fixing the system to the trolley. Before testing, the probe/flaw detector was calibrated using a calibration rail (Figure 2) having two sets of simulated defects. Two 8mm diameter holes were machined transversally through the rail head at depths of 23 and 27 mm. Another defect comprising of a 7.5mm diameter flat bottomed hole was machined from the rail end, at an angle of 70° to and 50 mm depth.

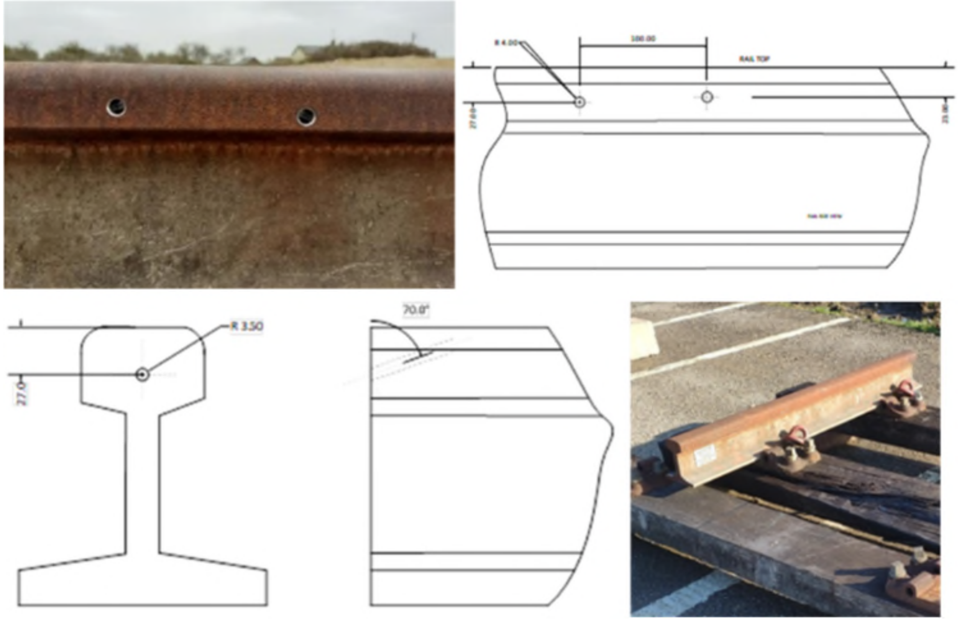


Figure 2. Calibration rail

The autonomous vehicle was the Warthog (ClearPath Robotics). This is an unmanned ground vehicle equipped with an UR10 robotic arm (Universal), and a suite of navigation and sensing instrumentation including IMU, Encoders, Lidar, GPS, stereo camera. Communications include Ethernet, USB, Remote control, and WIFI. The width of the wheelset is nominally narrower than that of the British railways gauge, requiring a RRV platform.

A simple electronic circuit simulated communications with the control base. It was constructed using off the shelf components such as Arduinos, and a modem to send an autogenerated text message to the server. The working principle is shown in Figure 3. It uses a 14v output from the Railscan 125 on flaw detection, reduced to 5 VDC for input to an Arduino/WIFI, which is programmed to issue and send to base a simple text code stating, “flaw detected”.

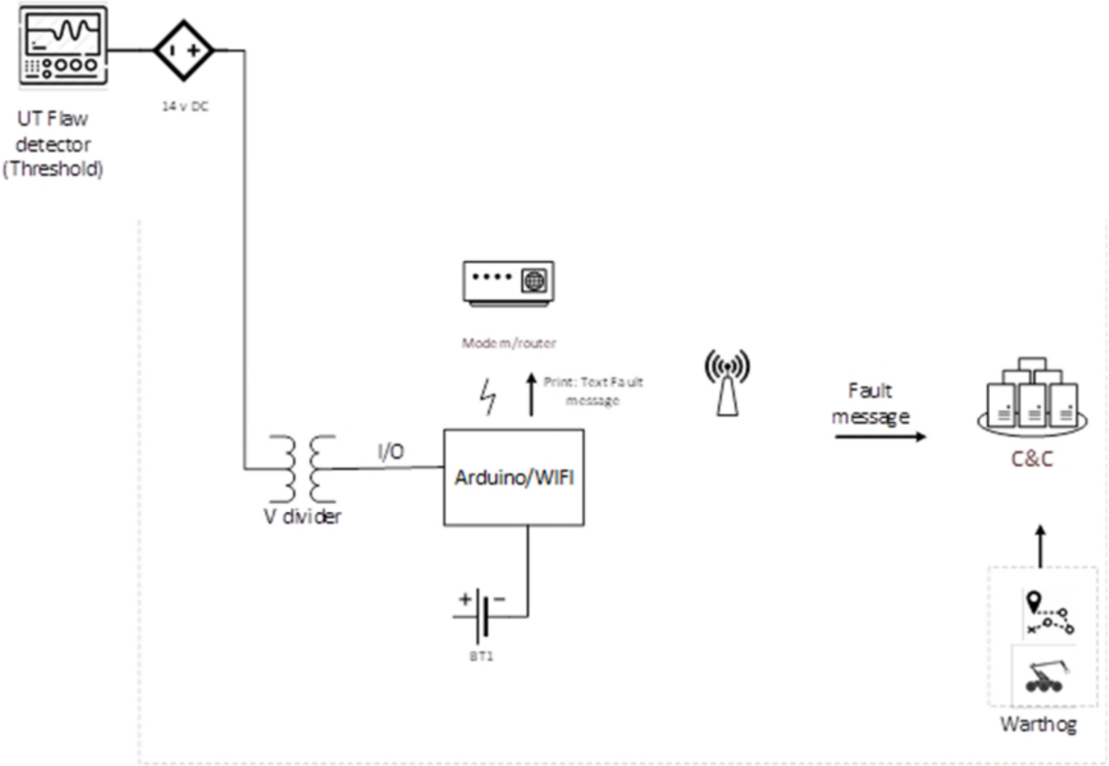


Figure 3. Flaw detection communications schematic.

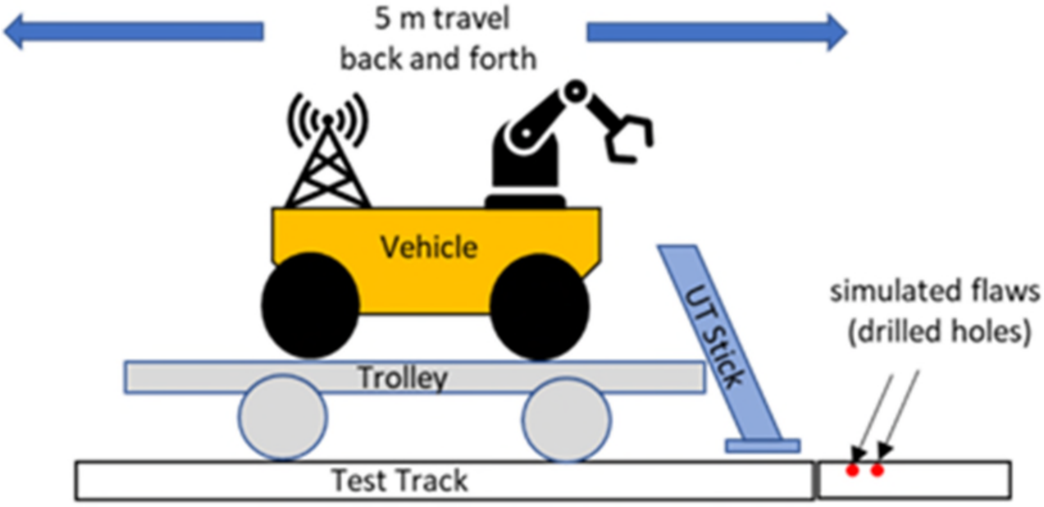


Figure 4. Test set up illustration.

Tests were conducted at Cranfield’s Rail and Innovation Test Area using an 18m decommissioned Vignole track panel, a realistic environment (TRL5).

The success of the inspection tests was defined as a function of repeated successful flaw GPS tagged detections.
Three on-track tests were conducted to demonstrate the repeatability. The prototype was programmed to navigate 5 m back-and-forth.

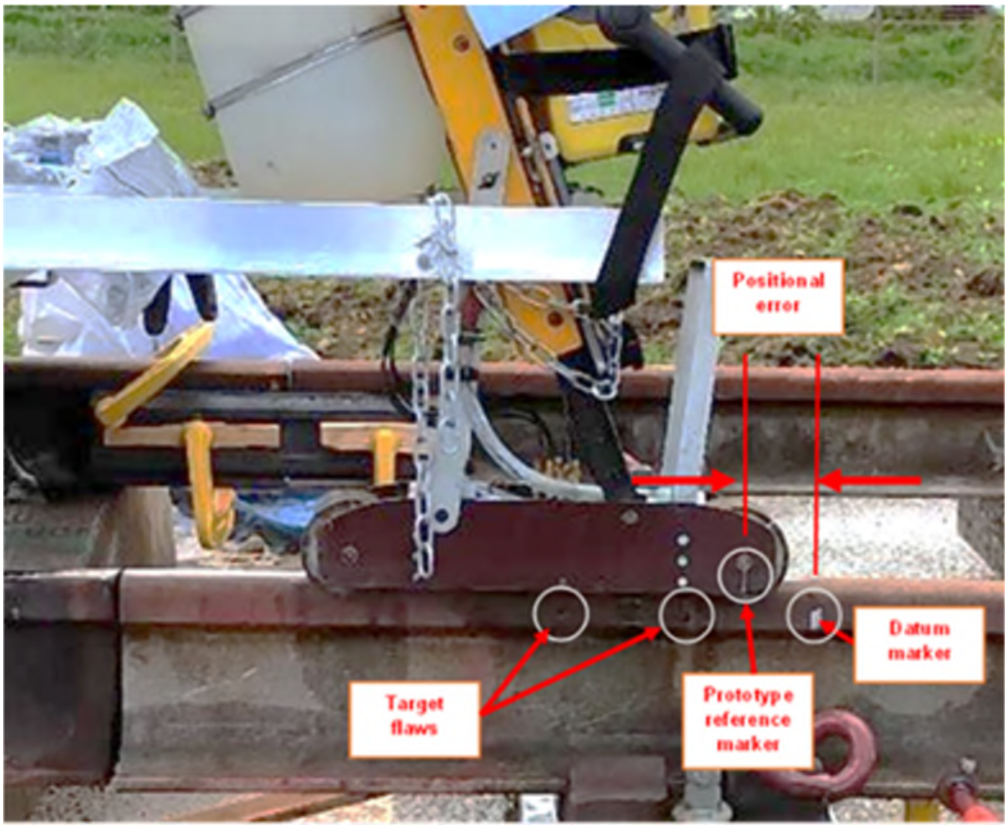


Figure 5. Prototype positional error measurement.

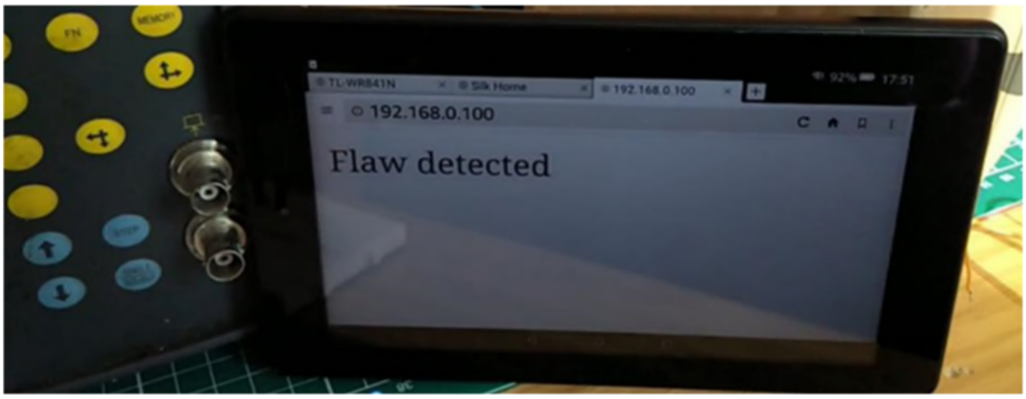
Its positional error was the distance from the datum reference to the probe end position (see Figures 4-5) and was measured by three methods: Global navigation satellite system (GNSS) real time kinematics (RTK) enhanced signal, odometry and by physical measurements of the start and return positions.

3 Results

In all three tests conducted, the inspection prototype successfully detected the 2 simulated target flaws, autonomously. With every detection, an audible alarm was triggered and confirmed detection to the operator, see Figure 6. The high detection rate was attributed to the relatively small number of tests, and the large size and shallow depth of the simulated defects, being 8 mm in diameter and 23 and 27 mm from the railhead top, respectively. Nevertheless, the research experiments were not designed to test the inspection method sensitivity, as this is a mature process already. Rather, it aimed to demonstrate the feasibility of autonomous ultrasonic inspections.

Figure 6 Flaw detector indicating detection

Communication to base was successful too. A tablet simulating being a command and control (C&C) base server, received fault detection messages from the Arduino micro-controller, see Figure 7.



Flaw detected

Figure 7 simulated flaw detection message

The vehicle did not return to the exact starting point every time. This was attributed to a combination of factors including GNSS uncertainties, slipping between the vehicle wheels and trolley rollers, skidding, the prototype dynamic response and mechanical backlash.

Figure 8 illustrates the path associated with each of the tests conducted, each colour representing one test. Up to 8 GPS satellites were available during testing, with over 1200 samples recorded per each test, with the estimated error being 2 cm.

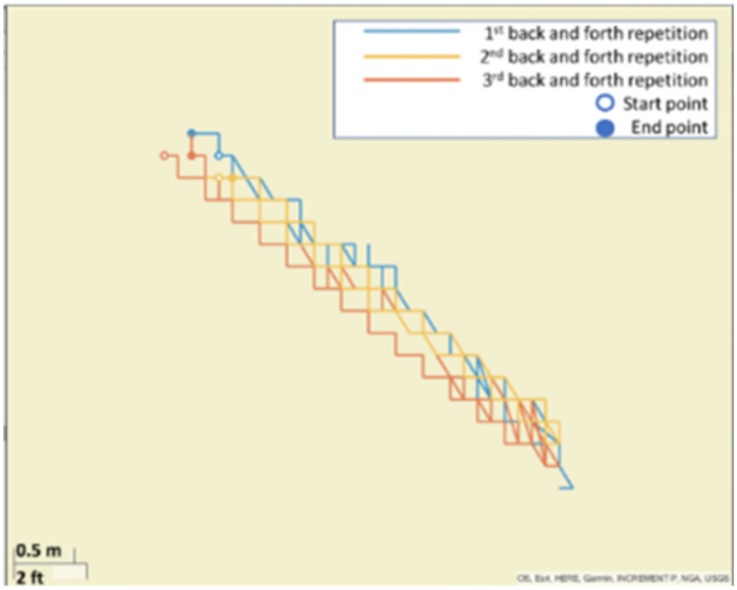


Figure 8 GPS analysis illustration. GPS path illustration for each test conducted

Table 1 shows the odometry output value of the prototype displacement per test. As seen, the longitudinal error ranged from 5 to almost 7 cm. It was noted that all measurements “drifted” on the backward displacement.

The odometry errors are attributed to dynamic response of the unmanned ground vehicle/trolley assembly which results in uneven contact of the wheels/rollers during displacement.

Test #	Displacement (m)		Error (cm)	
	Forward	Backward	Longitudinal	Positional
1	5.1816	5.2337	5.21	1.82
2	5.1998	5.2693	6.95	2.94
3	5.1704	5.2211	5.07	1.12

Table 1 Test odometry results

The marker measurements showed the longitudinal error for the three tests conducted were:

- 4 cm for test 1.
- 6 cm for test 2
- and 6 cm for test 3.

These measurements correlated well with those of the odometry system and therefore verified the positional accuracy of the prototype’s odometry.

4 Conclusions and Contributions

- Consistent fault inspection functionality on a section of test track has been successfully demonstrated using ultrasound inspections to a TRL 5.
- An autonomous prototype using both commercially available ultrasonics instrumentation and an unmanned vehicle platform was constructed, calibrated, and tested at a rail test facility.
- The prototype was able to successfully detect artificial rail defects of 8mm in diameter at depths of 23 and 27 mm in all the three repeat tests conducted. Detection was signalled using an audible alarm triggered by the ultrasound signals exceeding the flaw detector gate 1 threshold.
- Consistency of the inspection prototype positioning was verified by odometry, GPS and positional measurements relative to the vehicle start and end positions to the fault. There was good agreement with the results of the three measurements methods. The positional error ranged from 3 to 7 cm.
- Integration with autonomy command and control architectures was demonstrated by sending a simple plain text message to a receiving PC over LAN WIFI on fault detection trigger.

Limitations

- Architectural integration and communication of the different systems platforms and components comprising the prototype, e.g., UT inspection and the autonomous vehicle system computer, was only achieved at a higher level.
- Asynchronous positional information from different navigational and positional systems. The positional information obtained from odometry and GNSS refers to the UGV and did not account for the probe offset.
- Detected flaws were not GPS tagged. This was due to the lack of systems integration and architectures for message exchange between the prototype independent systems, as well as with the mission command and control system.
- The autonomy functionality of the inspection platform is still under development. Navigation of the autonomous vehicle was performed using standard GPS+RTK.
- The UGV was loaded manually by the operator using a remote joystick. An improved loading system design and machine vision tools could enable autonomous loading.
- The detection sensitivity of the prototype was not comprehensively tested. Simple tests were conducted demonstrating autonomy inspection principles. These tests inspected only one type of defect, size, and orientation. The defects were generous in size. A larger range of defects needs to be inspected to examine the systems sensitivity.
- Defects were not sized

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References

[1] "Rail Factsheet 2021," London, 2022. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1049929/rail-factsheet-2021.pdf

[2] M. Rahman, I. D. Cardenas, "Towards an Autonomous RIRS: Design, Structure Investigation and Framework," in 2021 7th International Conference on Mechatronics and Robotics Engineering, ICMRE 2021, 2021, pp. 164–168. doi: 10.1109/ICMRE51691.2021.9384846.

[3] M. Bobbe, "Reactive Mission Planning for UAV based crane rail inspection in an automated Container Terminal," 2020 Int. Conf. Unmanned Aircr. Syst. ICUAS 2020, pp. 1286–1293, Sep. 2020, doi: 10.1109/ICUAS48674.2020.9213854.

[4] M. Banić, Intelligent machine vision based railway infrastructure inspection and monitoring using UAV," Facta Univ. Ser. Mech. Eng., vol. 17, no. 3, pp. 357–364, Dec. 2019, doi: 10.22190/FUME190507041B.

[5] Y. Guo “An Efficient Rail Recognition Scheme Used for Piloting Mini Autonomous UAV in Railway Inspection," Proc. 2020 Int. Conf. Sensing, Diagnostics, Control. SDPC 2020, pp. 284–290, Aug. 2020, doi: 10.1109/SDPC49476.2020.9353162.

[6] I. Aydin, "Detection of Rail Defects with Deep Learning Controlled Autonomous UAV," 2021 Int. Conf. Data Anal. Bus. Ind. ICDABI 2021, pp. 500–504, 2021, doi: 10.1109/ICDABI53623.2021.9655796.

[7] Y. Z. Ayele "Automatic crack segmentation for uav-assisted bridge inspection," Energies, vol. 13, no. 23, Dec. 2020, doi: 10.3390/en13236250.

[8] E. Guclu, "Development of Vision-Based Autonomous UAV for Railway Tracking," 2021 Int. Conf. Innov. Intell. Informatics, Comput. Technol. pp. 120–125, Sep. 2021, doi: 10.1109/3ICT53449.2021.9581919.

[9] C. Anderson et al., "Autonomous Inspection System for Railroads," Apr. 2021. doi: 10.1109/SIEDS52267.2021.9483733.

[10] K. Chittal, "Autonomous rail inspection," in IEEE International Conference on Power, Control, Signals and Instrumentation Engineering, ICPCSI 2017, 2018,. doi: 10.1109/ICPCSI.2017.8392182.