**Concept of Operations**

**1. Scope**

This concept of operations document considers the development of an inspection robot designed for confined space operations within motorway gantries, The primary objective is to conduct internal inspection of these structures, providing an approach to reach areas which are not accessible to humans.

The project, developed as part of the 24/25 department of EEE MEng project, focuses on addressing technical challenges and industrial requirements for motorway gantries, from the project stakeholders: Amentum and National Highways.

This solution aims to improve safety of the inspection operator and to allow structural inspections to take place without the need of road closures. This is due to the nature of the operation which will also include the maintenance team and robot operators, which will be crucial for the success of the operation, they will oversee the maintenance of the robot and the navigation of the inspection robot within the infrastructure.

**2. Current system or situation**

Currently motorway gantries are only inspected externally, it is required that all structural aspects of signs and gantries are inspected [1], this includes foundations, columns, beam arms, connects and the “structural performance of any significant attachments” [1, section 2.2].

Unmanned aerial vehicles (UAVs) are sometimes used for gantry inspection, mainly external inspection. However, they are not suitable for internal inspection due to the confined space limitations [1]. Additionally, they are also disadvantageous regarding their battery life, hence significantly reducing operational times [2]. Hence, more research on UAV systems in confided spaces and battery technology is needed before being able to use this method for highway gantry infrastructure.

**3. Justification for and nature of changes**

There are several limitations to external only inspection, weather by human inspection or even with the use of UAVs, consisting of safety risks and operational inefficiency. Human inspectors are unable to safely traverse the length of the gantry, particularly not without closing the sections of motorway for significant periods of time. From a cost perspective, an internal robot inspection will be minimising road closures, significantly reducing traffic and related costs.

UAVs are limited to certain weather conditions (as they cannot operate in high winds) and internal space constraints. Additionally, their battery dependant system can bring inspection duration restrictions, requiring frequent battery charging or battery swaps, further decreasing system efficiency. Hence a tethered system will be more efficient to carry out operations.

Inspection of the inside of the gantry will allow for inspection of joints and structural components that cannot be seen externally, giving a more thorough inspection. Additionally, a robotic inspection can conduct several tests in spaces too small for humans to fit.

**4. Concepts for the proposed system**

The proposed system will inspect from inside the hollow motorway gantry structure, rather than external to it. The robot should be able to climb up inside the structure and move round inside the gantry with a human operator instructing it.

The key constraints on the system are the size of the operating area, with the gantry walls being 500 mm away from each other, and this gap going down to 300 mm at flanges. Additionally, the gantry may not be a square and the spacings in one direction may be much larger than this. The gantry is not a straight line, at point the system will have to navigate 90 degree turns.

The proposed system consists of two climbing units attached together with a turning mechanism to allow it to turn 90 degrees and navigate the gantry if needed. The system will require to maintain a stable grip on the walls and should be adapted to be used in varying surface conditions e.g. wet surfaces. Due to the modularity of the inching unit and continuum system, the robot will also operate at different infrastructure lengths and bends; as its semi-autonomous nature will allow the operator to have full control of the movement and bends of the robot.

To assist both with navigation and inspection, the system will be equipped with a sensing system. This sensing system will enable the robot to navigate through the gantry by detecting obstacles, measuring distances, and providing real-time feedback for the operator to adjust movement. This real-time feedback will be provided by a human-robot-interface system, which will be developed to provide localisation of the robot real-time. This will be a wired system attached to a monitor which will give visual representation of the location of the robot, by using pre-determined information on the structure to be inspected. However, this visual can also be switched to a live camera on board to deliver specific inspection of the damages of gantry elements.

Furthermore, the system will incorporate Non-Destructive Testing (NDT) methods to assess the structural integrity of the gantry. These testing techniques will allow the detection of internal flaws or defects, such as wall thickness, corrosion and wall coating damage. This can all be tested without causing damage to the gantry interior.

The whole system will be connected to a tethered connection for power and data transmission. This tether will provide uninterrupted electricity to the robot, eliminating the need for battery changes, enhancing operational times.

**5. Operational scenarios**

The system must navigate inside of a motorway gantry starting at any orientation. It should pause at various critical points, such as flanges, to inspect any gantry damages using the camera and gather any useful sensor readings for navigation. The robot must be able to turn a maximum of 90 degrees for any number of corners, and continue to move along the gantry, ensuring all the expected areas of the gantry are reached and thoroughly inspected.

An operational scenario that could introduce operational difficulties, is obstruction of the camera. As this element is used for the main visual inspection of any damages, obstruction caused by dust or condescension can cause the operation to fail, hence maintenance of the camera system is important, and operation must be started again with a clean camera.

The robot must also be able to route through different materials such as concrete, steel and painted steel, of which can be wet or slippery. This will further enhance the complexity of the system and operation. In the event of an operational failure, which could be due to a mechanical failure or the adhesion method slipping and losing grip, the system should still be retrievable. This scenario highlights the importance of having a robust system to maintain safety and operational efficiency.

**Sources**

[1] “CS 450 Inspection of highway structures,” [*www.standardsforhighways.co.uk*](https://www.standardsforhighways.co.uk). <https://www.standardsforhighways.co.uk/search/html/c5c2c3e5-f7f3-4c94-8254-184e41ccd1a0?standard=DMRB>

[2]“Drone Inspections: A Comprehensive Guide,” *Energy-robotics.com*, Jun. 04, 2024. <https://www.energy-robotics.com/post/drone-inspections-a-comprehensive-guide>