CHAPTER 10

THE ROBO-SPECT EU PROJECT: AUTONOMOUS ROBOTIC TUNNEL INSPECTION

R. MONTERO, J. G. VÍCTORES, E. MENÉNDEZ AND C. BALAGUER

RoboticsLab, Universidad Carlos III de Madrid; jcgvicto@ing.uc3m.es

ROBO-SPECT is a European 7th Framework project funded under the ICT programme on Robotics Use Cases (contract No. 611145), implemented by 10 partners from 6 European countries. Driven by the tunnel inspection industry, its main objective is to adapt and integrate recent research results in intelligent control in robotics, computer vision tailored with semisupervised and active continuous learning and sensing, in an innovative, integrated, robotic system that automatically scans tunnel intrados for potential defects on the surface and detects and measures radial deformation in the cross-section, distance between parallel cracks, cracks and open joints that impact tunnel stability.

1 Introduction

One of the greatest challenges engineers face is the inspection, assessment, maintenance and safe operation of the existing civil infrastructure. This includes large-scale constructs such as tunnels, bridges, roads and pipelines. In the case of tunnels (water supply, metro, railway, road, etc.), they have increased in both total length and number, and will continue to do so. Furthermore, some tunnels still in service were completed over 50 years ago, with the existing construction and materials technology.

Only in Japan in 2006, the number of active tunnels was up to 9000 (Mashimo, 2006), with tunnels such as the Seikan Tunnel, which is 54 km long and partially below the seabed (Ikuma, 2005). Figure 1 depicts the evolution of Japanese tunnels in terms of number and length until 2006.

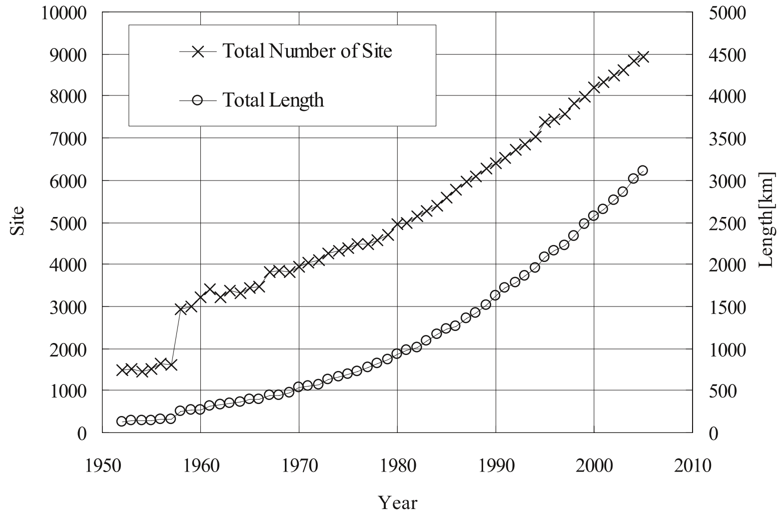

Fig. 1. Changes in the number and total length of road tunnels in Japan (Mashimo, 2006)

Tunnel environments are characterized by dust, humidity, and absence of natural light. Artificial and natural impacts, change in load criteria, or the simple effect of ageing, make tunnels require inspection and maintenance. These operations are commonly performed by human operators, taking time and expertise, without guarantee quality control. The previous examples highlight the need of automated, cost-effective and exhaustive inspection of tunnels that prevents such disasters (Balaguer, 2014). In this chapter, we present the current works and future objectives of the ROBO-SPECT EU research Project within this area.

2 The ROBO-SPECT EU Project

ROBO-SPECT is a project co-funded by the European Commission under FP7-ICT (Robotics topic), that started in October 2013 and will finish in October 2016, and is coordinated by the Institute of Communication and Computer Systems (Athens, Greece). The objective of ROBO-SPECT is to provide an automated, faster and reliable tunnel inspection and assessment solution that can combine in one pass both inspection and detailed structural assessment that does not interfere with tunnel traffic (Montero, 2015). The robotic system will be evaluated at the research infrastructure of VSH in Switzerland, at London Underground and at the tunnels of Egnatia Motorway in Greece and the system is expected to:

- Increase the speed and reliability of tunnel inspections.
- Provide assessment in addition to inspection.
- Minimize use of scarce tunnel inspectors, while improving the working conditions of such inspectors.
- Decrease inspection and assessment costs.
- Increase the safety of passengers.
- Decrease the time tunnels are closed for inspection.

In summary, the needs to which ROBO-SPECT will be replying are the following (Loupos, 2014):

- High cost of new tunnel constructions (need for inspection, assessment and repair of existing).
- Transport demand is highly increasing and cannot cope with the rate of transport infrastructure and high tunnels uptime.
- Inspection and assessment should be speedy in order to minimize tunnel closures or partial closures.
- Engineering hours for tunnel inspection and assessment are severely limited.
- Currently tunnel inspections are predominantly performed through scheduled, periodic, tunnel-wide visual observations by inspectors who identify structural defects and categorize them manually (manual, slow and labor expensive process).
- Un-reliable classification of the liner conditions and lack of engineering analysis.

3 The ROBO-SPECT architecture and design

The ROBOS-SPECT system is composed of three different components that will allow the complete inspection and assessment of the tunnel and will provide all the functionalities to the final users. The first component is the robotic system. The robotic system will perform the inspection inside the tunnel and incorporates all the different sensors that will be used during the inspection. The second component is the Ground Control Station (GCS) that will work as a central unit to monitor the robot mission and communicate with the platform. The GCS works also as a link between the robot and the third component, the Control Room (CR). The CR will be equipped with the PCs that contains the Structural Assessment Tool. This software will use the inspection results to generate a complete assessment report about the tunnel state.

3.1 Robotic system

The ROBO-SPECT robotic system design is based on an industrial wheeled robotic system able to extend an automated crane to the dimensions of the metro and motorway tunnels. It is equipped with a robotic arm to place with high accuracy a specifically designed ultrasonic sensors to measure width and depth of detected cracks inside the tunnel lining. The defects inside the tunnel are detected using a series of cameras and a 3D laser profiler to detect deformations on the tunnel lining. Figure 2 presents the actual design of the robot and the different components that will be described. The mechanical design of the robot is inspired by the robot used on the Tunconstruct EU project (Victores, 2011), that uses a similar vehicle, crane and robotic arm configuration.

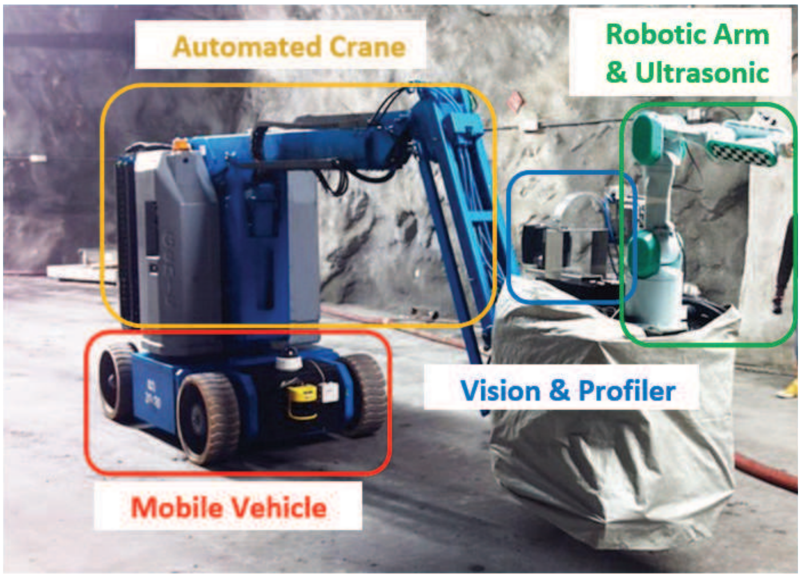

Fig. 2. ROBO-SPECT robotic system

3.1.1 Mobile vehicle

The robotic platform will be able to move on road and rail to cover the applicability of the robotic system in the two use cases chosen for the project:

motorway and metro tunnels. This mobile vehicle is able to navigate autonomously and perform collision avoidance through the tunnel using a pair of 2D range laser sensors, one in the front and one on the back of the vehicle. The navigation is performed using SLAM by placing a series of reflective beacons in known positions inside the tunnel. These beacons are detected by the laser sensors and used to update the localization of the robot in the tunnel. A real 2D map of the navigated tunnel section is created at the end of the inspection, and can be used to improve navigation on subsequent inspections.

3.1.2 Automated crane

The crane of the vehicle has been automated using encoders inside the joints in order to control the crane tip position and orientation. The joints of the system are equipped with special brakes to minimize the oscillation and vibration of the parts. The crane tip is designed to carry a platform with a robotic arm equipped with ultrasonic sensors and a series of cameras and a 3D laser profiler. The behavior of these components is described below. The crane can position the mentioned platform at maximum 10 meters height from the ground, which is enough for the vast majority of tunnel geometries.

3.1.3 Robotic arm

The robotic arm placed on the crane platform is the Mitsubishi PA-10, a 7 Degrees Of Freedom (DOF) industrial manipulator. The 6DOF provides the arm with full position and orientation capabilities, and the additional degree of freedom produces redundancy to provide the robotic arm with collision avoidance capabilities. The workspace of the robot cover from a few centimeters to 1 meter approximately from the base of the arm to the end-effector. A special set of ultrasonic sensors will be placed at the tip of the robot. The mission of the robot is to place the ultrasonic sensors on a crack inside the tunnel to perform width and depth measurements. In order to calculate a safe trajectory to the final point, a 2D range laser sensor is attached to a link of the arm to scan the surroundings of the crack position and create a 3D point cloud of the wall before moving the system.

3.1.4 Vision system

The ROBO-SPECT system is equipped with two pair of 9.1MP cameras to detect different defects inside the tunnel walls during the inspection. This cameras are placed on the crane platform to be able to be positioned at a controlled distance to the wall. The first pair of cameras are designed to be able to identify a set of different defects commonly found on tunnels such as spalling, staining, exposition of reinforcement, water leakage, white deposits, etc… These defects are detected using machine learning techniques like Convolutional Neural Networks (CNN) trained with real images of tunnel defects. The other pair of cameras are designed specifically to detect cracks in real time, and they will be able to detect and estimate the 3D position and orientation of the crack inside the tunnel. This information is then passed to the robot to move the crane to the crack surroundings first, and move the robotic arm to place the ultrasonic sensors later. The cameras will be capable of taking a stereo image of the crack to be used later on the structural assessment tool for characterization purposes.

3.1.5 Laser profiler

Furthermore, a 3D laser profiler is placed on the crane platform to extract a 3D section of the tunnel. The 3D laser profiler used in ROBO-SPECT is the Faro Focus3D X 130. This profiler will be used to detect tunnel structural deformation with an accuracy of ±2 mm. The laser scanner is able to produce a 360 degree point cloud of one million points/second scanning rate.

3.1.6 Ultrasonic sensors

At the end of the robotic arm a set of ultrasonic sensors will be attached. These sensors are designed specifically for the ROBO-SPECT project to measure the width and depth of the crack while in contact with the tunnel wall. The depth of the crack is measured using two piezo-electric ceramic transducers. To perform the depth measurement, the transducers will be positioned on each side of the crack by the robotic arm. Regarding the width measurement, a newly created fiber-optic sensor will be used. The sensor will be positioned using a special XY positioning stage attached to the robotic arm. When all the measurements are made, the robotic arm remove the sensors from the wall and the inspection continues.

3.1.7 Global controller

In order to control all the different subsystems of the robot, a general controller will be developed to manage the communications between parts. All the different components (mobile vehicle, crane, cameras, etc…) will be connected to a common network inside the robot to receive the commands and provide the measurements and state of the systems. This general controller will receive a mission from the Ground Control Station and provide the protocol to command the robot to perform the requested inspection mission autonomously. It will be able to navigate the robot through the tunnel, detect when a crack has been spotted and perform the necessary joint movements to place the ultrasonic sensors on the crack and perform all the required measurements. The controller will update the GCS with the state of the mission and the inspection data gathered.

3.2 Ground Control Station

The Ground Control Station will be a computer component outside the robot that will be in contact with it. The GCS will provide a graphical user interface and it will work as a human-machine interface (HMI). From the GCS the user can provide a mission to the robot and retrieve the state of the mission while the robot is inside the tunnel. The communication between the robot and the GCS will be based on a wireless connection.

The GCS will be in contact with the Control Room as well, and depending on the tunnel and the final user, the connection with the CR could be wireless, access to the nearest access point of the infrastructure network or internet, or a direct connection if the end-user will process the data once back in the company HQ. This communication provides the CR with all the inspection data gathered by the robot to process later using the structural assessment tool.

3.3 Control Room

The Control Room is the last component of the ROBO-SPECT tunnel inspection system. The CR represents the site where all the data gathered by the robot will be processed. This processing will be made by the Structural Assessment Tool (SAT), a software created inside the project scope to store, graphically represent and process all the inspection data. The SAT will allow the end user to see the generated maps of the tunnel, the 3D slices computed by the laser profiler, information about the different defects detected and their position inside the tunnel. It will use all the mentioned data to produce a complete assessment report of the structural state of the system that will be presented to the end-users. The SAT will be able to use also information from multiple inspections of the same tunnel separated in time to study the rate of deformation of the lining or the evolution of the cracks and other defects.

4 Future developments

At this stage of the project, the current developments taking place right now are focused on:

- Finalizing the global controller design and test all the communication between components to perform field tests and evaluate the overall system behavior. This will allow to define process accuracies on navigation and positioning of the different robotic parts, as well as precisions on the final data gathered by the sensors.

- Performing simulations of the complete system to explore different inspection procedures. The simulation of the system is being developed using Gazebo robotic simulator under ROS environment. Figure 3 shows the simulated system inside a Gazebo tunnel environment.

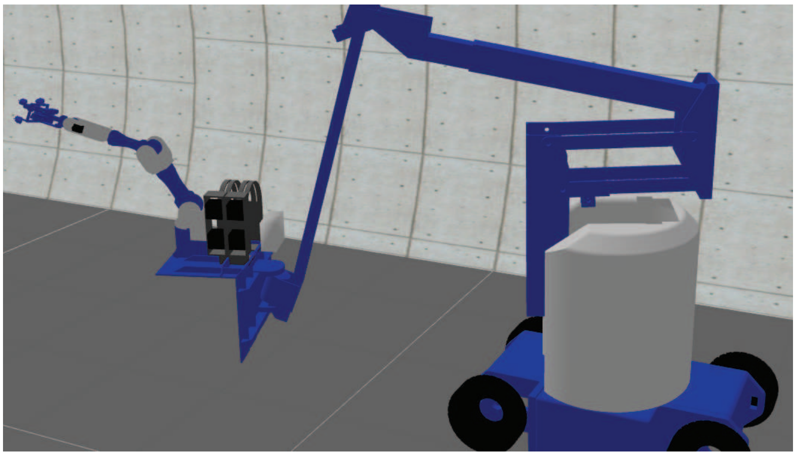

Fig. 3. Gazebo simulation of the ROBO-SPECT system

- The placement of contact sensors at the end of the ultrasonic sensor frame is being developed. There will be four contact sensors on the rigid piece attached to the robotic arm where the ultrasonic sensors are placed. These sensors will allow the robotic arm controller to know when the mechanical piece is touching the wall and detect if the four sensing points are in contact with the wall. This information will be used to control the orientation of the robotic arm end-effector to achieve a good positioning of the sensors that provides the best scenario for the measurements.

Apart from the specific points described before, the project partners are working continuously on different parts of the robot to improve the control and the autonomous behavior. The robotic drivers and the navigation software are being in constant development to provide better control of the different parts and better navigation autonomy of the mobile vehicle.

Acknowledgements

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