Robot-aided tunnel inspection and maintenance system by vision and proximity sensor integration

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ABSTRACT

This article describes an unprecedented alternative to manual procedures for the application of advanced composite materials, such as Fiber Reinforced Polymer (FRP) and epoxy resins. A complete mobile integrated system is presented for the inspection and maintenance of concrete surfaces in tunnels. It allows performance of operations with minimum interference on passing traffic. The core of this system resides in a specially designed light-weight robotic tool, which is sensed and automated for processes. Sensing includes vision and a laser telemeter to assure precise inspection, superficial preparation, and composite application. The designed interconnection flange allows simple and robust attachment of the tool to a robotic arm's tip. The robot–tool set is to be mounted on a standard articulated lift platform. Therefore, an operator can direct the platform and the robot–tool set's operations from a control station placed at ground-level, in a wheeled vehicle on which the articulated lift platform is mounted. A graphical Human–Machine Interface (HMI) has been developed for the system. It allows the operator to identify fissures for the injection of epoxy resin, and weakened surfaces for FRP adhesion. Actual procedures are planned and performed by the system's automatic components.

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1. Introduction

Tunnels nowadays are designed and built to last hundreds of years. However, change in use, new load criteria, and impact and damage caused by natural and human factors can drastically reduce a tunnel's service life. Moreover, as tunnels throughout the world and in Europe in particular become older, matters of inspection and maintenance adopt an ever increasing degree of importance [1].

Inspection and maintenance operations in tunnels depend heavily upon time and space constraints: the tunnel's intrinsic conditions (reduced space, possible existence of service pipes), traffic flow, the presence of aerial electric cable in railway tunnels. Working conditions in these subterranean infrastructures can be slow and tedious. Dust, humidity, and complete absence of natural light create uncomfortable and at times unhealthy working conditions. Efficiency and stigma of operators gradually reduce throughout the day in these conditions, incrementing the risk of damage, hazard, or incorrectness of procedures. Additionally, in many cases traffic flow must be cut for operations to be performed, as scaffolds must be mounted and security assured. Any attempt to automate operations performed in these subterranean infrastructures will drastically improve short and long-term productivity, as well as supporting operators in their task [2][3].

A great range of factors can cause need for maintenance or reparation operations. Two of the most important of these factors will be treated:

- Fissure formation due to deformation caused by excessive load or caused by bending moments induced by heterogeneous soil and rock conditions [4]. Although current legislations tolerate the existence of small fissures, their real dimensions should never exceed a small, reduced range. Reinforced concrete's interior metal infrastructure should never be exposed to ambient atmosphere.
- Loss of quality of the infrastructure's surface due to lack of correct metal-conglomerate adhesion. This may be caused by external forces that erode the external surface, or by general or local corrosion [5].

2. Maintenance operations

Presently, practically all inspection and maintenance operations in tunnels are performed manually. Frequently, traffic flow must be cut, and scaffolds mounted, implying the subsequent loss of global productivity. The maintenance operations studied for automation call for the following set of tasks: superficial preparation, fissure injection, and FRP composite adhesion.

2.1. Superficial preparation

This includes all of the processes needed to eliminate concrete in bad state. Loss of mechanical capacity or of stability within the rest of