Inspection Robotics for Harsh Environments, Industrial Applications and Infrastructures

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***Abstract*—In this document, a family of robots designed to be used in harsh environment is presented. The robots have been developed with the goal of being deployable into a wide number of industrial applications especially when confined or harsh environments need to be inspected. The ability of withstanding high temperatures and operate in hazardous environments, or to access places with small apertures is a set of features covered by the robots presented here. Modularity and scalability drove the design of the presented prototypes with the aim of creating a robot family that can be easily employed in a variety of scenarios such as infrastructure inspection, nuclear and conventional power plant maintenance, nuclear waste management or, eventually, disaster recovery.**

***Index Terms*—robotics, automation, inspection, predictive maintenance**

Fig. 1. Prototype of the inspection robot assembled with 5 modules

I. Introduction

Many activities can benefit from robotic inspection especially when this lead to an increase of the safety for the human operator. robots can move into environments too dangerous to be accessed such as: nuclear power plants, nuclear waste sites, vessels, tanks and pipe lines. In this context the use or implementation of robotic systems can represent a game changer approach: robots are not a replacement of the human operator but, on the contrary, they can be an innovative tool to be able to safely perform tasks or activities that were not possible with traditional methods.

At the same time, ageing infrastructure is an emerging threat in both civil and industrial fields. The risk of failure increases when old infrastructures or facilities keep operating beyond their expected lifetime. Under these circumstances an increased inspection and maintenance activity is unavoidable.

The benefits of an accurate and well defined inspection plan are an increase of safety and efficiency leading to an overall advantage in economical terms when the lifetime of the infrastructure can be safely extended [5]. Often old infrastructures have not been designed for being inspected or for satisfying safety requirements for human inspectors not equipped with monitoring sensors [7].

In this paper some of the robots developed by IIT for inspection in industrial environments are presented. Many inspection and maintenance applications can take advantages from the use of robots, but it is difficult to design a robot to be employed in all the possible inspection scenario. This paper proposes the design of an eco-system of robots that can fulfill many of the above mentioned tasks. Furthermore robotic inspection is a powerful tool for predictive maintenance once integrated with data analysis or machine learning approaches.

II. Robotics eco-system

A. Snake-like robot

Inspection robots can be specifically designed for a particular task or being developed for a more general purpose. Facing the problem of accessing large volumes through small openings such as for tanks or vessels snake-like robots could be the solution. In particular a hyper-redundant robot, shown in Fig. 1 and Fig. 2 has been developed. The robot consists of an actuation box, where linear actuators are located and an arm composed by several modules. Each module is made by a joint and a link with a diameter of 140mm; the module length is 500mm and up to 10 modules can be connected together. A customized end-effector, e.g. a gimbal with a camera or other

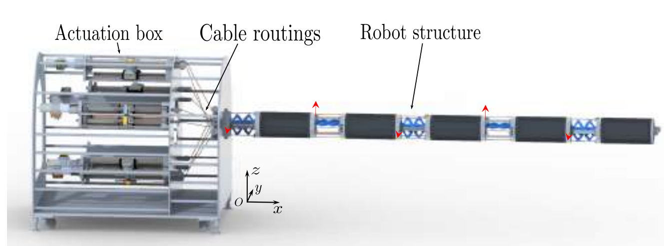
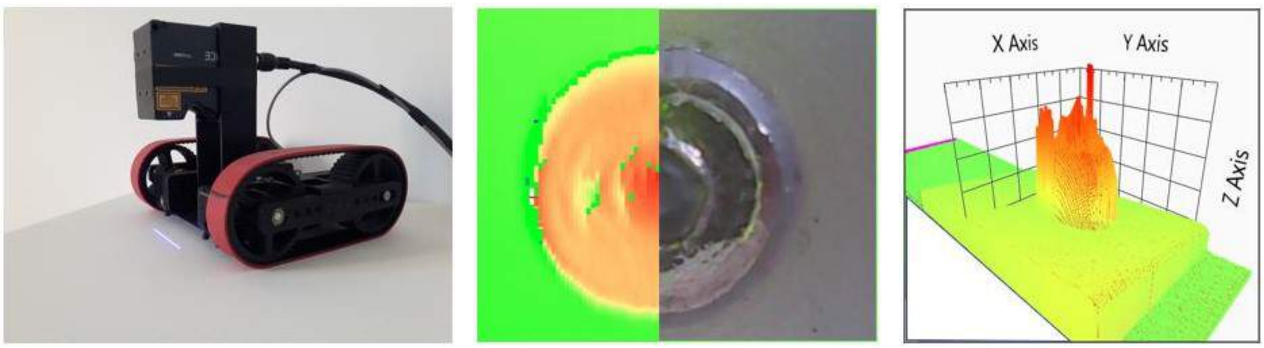


Fig. 2. CAD of hyper-redundant robot. Each actuator drives one DOF of the robot.

(a) Crawler robot overview. (b) Inspection of a electric generator. (c) Climbing a civil building.

Fig. 3. Crawler robot with magnetic adhesion. It is able of carrying on camera and sensors to inspect small spaces or climbing over metallic structures such as iron beams



(a) Rivetbot: system overview. (b) 2D rivet reconstruction versus real rivet. (c) 3D rivet reconstruction.

Fig. 4. Crawler robot can benefit from integration with advanced sensors and artificial intelligence to automatically perform inspection of elements such as rivets.

sensors, can be connected to the tip of the robot. In this design, one motor for each DOF has been used keeping all the driving cable in tension without using any compliant joint [3], the load capacity has been maximized removing all the additional devices such as transfer pulleys and compensation tendon systems; this solution allows to assembly the robot in a modular manner varying its architecture according to the task to be faced.

B. Crawler with magnetic adhesion

The crawler robot, shown in Fig. 3.a, has been originally developed for the inspection of power generators. With an height of just 20 mm, the robot is able to move along metallic surfaces, thanks to the magnetic adhesion, and carrying on sensors and other tools [8]. The robot is equipped with a camera, light and in its general-porpuse version it has been adapted for new applications such as iron beam inspection of civil infrastructures (as Shown in frame 3.c).

C. Rivet inspection

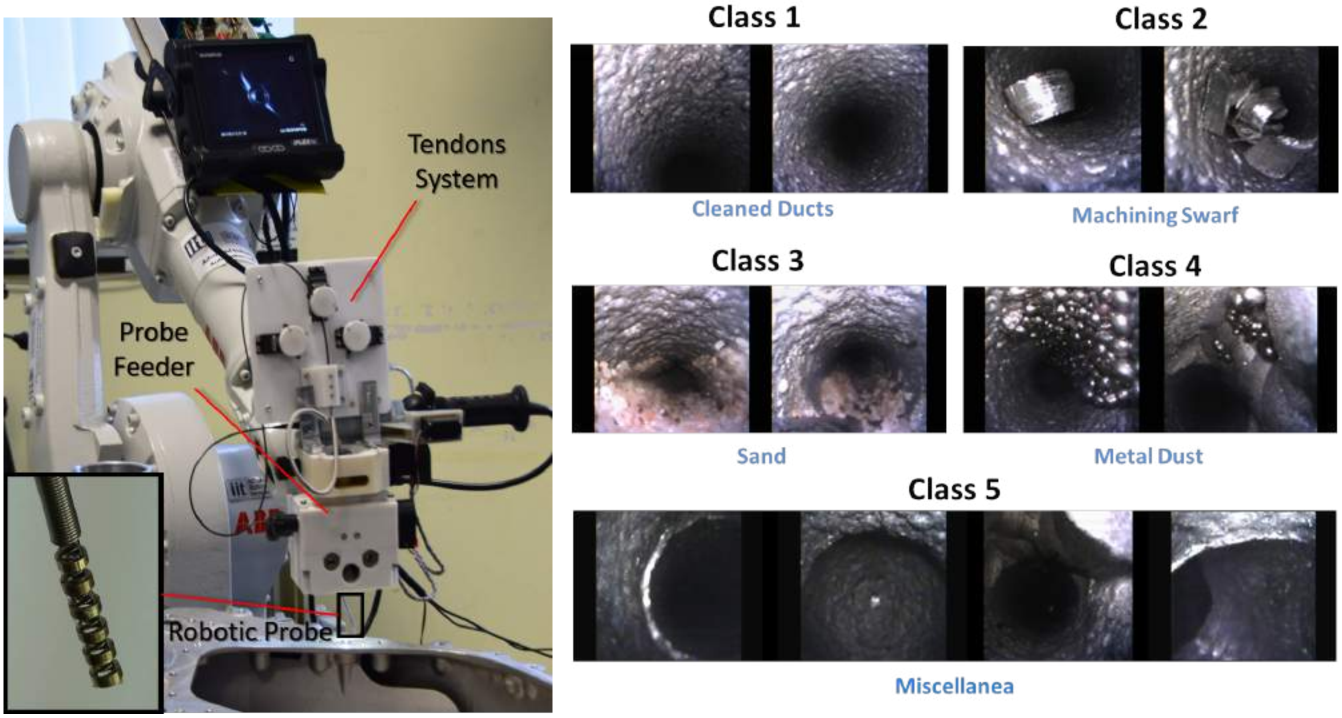
Robots can benefit from integration with advanced sensors and artificial intelligence to inspect mechanical elements and determine their integrity. This is the case of the robot [2] shown in Fig. 4. In this application, the system performs an automatic inspection of rivets. This is a very common task that represents a key activity in many industrial fields ranging from aerospace to civil infrastructure maintenance. A robot equipped with the proper sensors and a dedicated algorithm can perform a sanity check on rivets. The robot has on board a laser scanner, a camera and an actuated hammer with a microphone, so it can automatically inspect rivets. The proposed method combines different techniques to discriminate between properly assembled rivets and issued rivets: both the analysis of the rivet profile made using the laser scan and the analysis of the sound response of the rivet to a small mechanical exciting pulse have been combined: the output of the analysis is a binary classification of good and bad rivets.

D. Robotic endoscope

The robotic system, shown in Fig. 5a, can be used to inspect oil ducts of gearbox housing [6, 4]. The inspection of small ducts using endoscopic devices is a crucial task for specific industrial sectors such as the avionic industry in which the quality of the final product must meet very high standards. The automatic system is actuated by a robotic arm that moves the endoscope with a micro camera inside the gearbox duct, while a deep learning based spatio-temporal image analysis module detects, classifies and localizes defects in real time [1]. Some images acquired inside the ducts are shown in Fig. 5b.

III. Conclusion

In this extended abstract, an overview of robots to be used for industrial inspection tasks has been presented. The



(a) Overview of the inspection system.

(b) Defects images acquired by the endoscope inside the oil ducts of the gearbox.

Fig. 5. An intelligent duct inspection system integrates robotic devices with machine learning to automatically detect defects in oil ducts

use of robots for inspection tasks can open new perspective on maintenance and increase the safety of human operators. This approach demonstrates to be extremely powerful and efficient when the physical inspection is performed in synergy with the use of automatic data analysis and machine learning approaches.

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REFERENCES

[1] C. Beltrán-González, M. Bustreo, and A. Del Bue. External and internal quality inspection of aerospace components. *2020 IEEE 7th International Workshop on Metrology for AeroSpace (MetroAeroSpace)*, pages 351–355, 2020. doi: 10.1109/MetroAeroSpace48742.2020.9160103.

[2] C. Canali, A. Pistone, C. Gloriani, P. Guardiani, D. Ludovico, and D.G. Caldwell. Rivet inspection with multi-sensor robotic system. *INES 2020 - IEEE 24th International Conference on Intelligent Engineering Systems, Proceedings*, pages 61–65, 2020. doi: 10.1109/INES49302.2020.9147186.

[3] D. Ludovico P. Guardiani A. Pistone J. Lee F. Cannella Darwin G. Caldwell C Canali. Modeling cable-driven joint dynamics and friction: a bond-graph approach. *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2020.

[4] P. Guardiani, C. Canali, A. Pistone, S. Leggieri, C. Gloriani, N. Rahman, F. Cannella, and D. Caldwell. Novel integrated robotic system for tiny duct inspection. In *Procedia Manufacturing*, volume 17, pages 342–349, 2018.

[5] Barrie Houlihan. Europe's ageing infrastructure: Politics, finance and the environment. *Utilities Policy*, 4(4):243 – 252, 1994. ISSN 0957-1787. doi: https://doi.org/10.1016/0957-1787(94)90015-9.

[6] S. Martelli, L. Mazzei, C. Canali, P. Guardiani, S. Giunta, A. Ghiazza, I. Mondino, F. Cannella, V. Murino, and A. Del Bue. Deep endoscope: Intelligent duct inspection for the avionic industry. *IEEE Transactions on Industrial Informatics*, 14(4):1701–1711, 2018.

[7] Risako Morimoto. Estimating the benefits of effectively and proactively maintaining infrastructure with the innovative smart infrastructure sensor system. *Socio-Economic Planning Sciences*, 44(4):247 – 257, 2010. ISSN 0038-0121. doi: https://doi.org/10.1016/j.seps.2010.07.005.

[8] A. Pistone, C. Canali, C. Gloriani, S. Leggieri, P. Guardiani, and D.G. Caldwell. Reconfigurable inspection robot for industrial applications. *Procedia Manufacturing*, 38:597–604, 2019. doi: 10.1016/j.promfg.2020.01.075.