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Compact Magnetic Wheeled Robot for Power Plant Inspection

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MagneBike: Compact Magnetic Wheeled Robot for Power Plant Inspection

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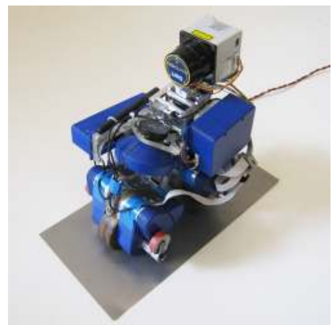
Abstract—**The MagneBike robot is a magnetic wheeled robot designed for the inspection of ferromagnetic structures in power plants, especially steam chests. This video first presents the robot's locomotion concept, *i.e.* two aligned magnetic wheels integrating lateral lever arms, that allow the robot to pass over complex combinations of obstacles. Laboratory and field experiments show the high mobility of the robot. This video also describes the localization and mapping strategy that consists in combining 3D odometry with 3D scanning and scan registration. An animation of the 3D reconstruction of the environment shows that the localization procedure allows to provide the necessary 3D visual feedback for the remote user or for inspection mission planning.**

Index Terms—**Inspection robot, Field robot, Locomotion, Magnetic wheels, Localization, 3D odometry, Design and Integration.**



(a)

(b)

Fig. 1. a) MagneBike: magnetic wheeled inspection robot equipped with a 3D laser range finder. b) Industrial version of the MagneBike (without 3D range finder).

I. INTRODUCTION

Mobile inspection and maintenance robotics is a fast growing industrial market. One of the main advantages of mobile robots is that they can reach locations inaccessible by humans because of size constraints, temperature, immersion in liquids or safety reasons. Robots also allow to decrease the inspection time and costs if operations like building scaffoldings, excavating, disassembling or moving cumbersome parts into workshops, can be avoided. Furthermore, storing the measurements of systematic inspection procedures improves the traceability of defects, the prediction of the constructions lifetime and allows to optimally plan their repairing. Repairing can even be done *in situ* if the robot is equipped with the appropriate tools.

In this framework, the MagneBike inspection robot has been developed. The robot, depicted in Figure 1, is a magnetic wheeled robot capable of inspecting power plant facilities, focusing on the inner casing of steam chests for a specific case study.

II. LOCOMOTION

Due to size constraints and the complex shape of the environment, the first challenge was to develop a compact system with climbing and obstacle passing capabilities. The innovative locomotion concept presented in this video consists of two aligned magnetic wheel units with integrated lateral lever arms. These arms have two complementary functions: they can be used to slightly lift off the wheel in order to locally decrease the magnetic attraction force when passing over concave edges or to laterally stabilize the robot when gravity is unfavorable. Steering is ensured by an active degree of freedom on the front wheel and surface adaptation is provided by a free joint on the fork. This locomotion concept has a very high mobility and enables driving on complex 3D industrial environments that are not necessarily designed for robots. The robot can climb vertical walls, follow circumferential paths inside pipe structures and can also pass over complex combinations of convex and concave step obstacles with almost any inclination regarding gravity. It requires only limited space to maneuver as it can turn on spot around the rear wheel. The compact and lightweight climbing robot (185 $\times$ 143 $\times$ 236 mm^3, 3.5 kg) and its high mobility locomotion concept are presented and analyzed in detail in [1].

The video shows the high mobility of the robot through experimental tests as depicted in Figure 2. The robot passes over an overhanging gap-type obstacle and climbs a double overhanging step where it has to simultaneously activate the front and rear lifter arms. The robot mobility is also evaluated through field experiments in the steam chest environment for which it has been designed: the video shows the robot following a circumferential path in a horizontal pipe, but also in an inclined pipe where it has to use the lifter arms for lateral stabilization.

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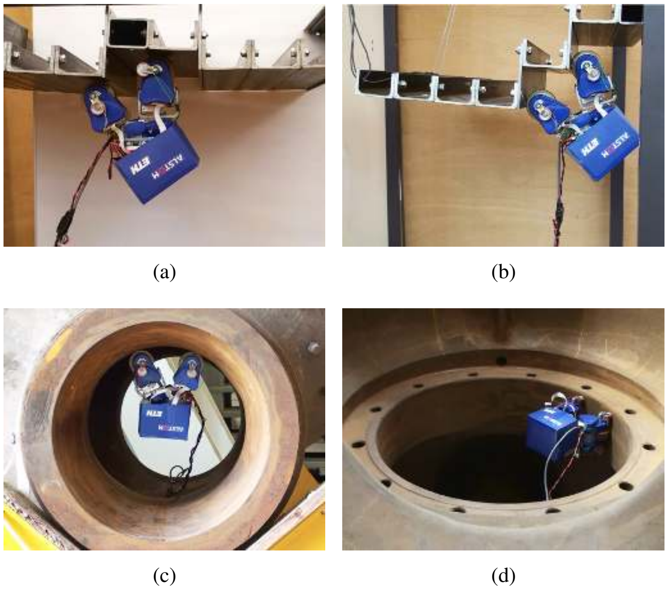

Fig. 2. Laboratory tests: the MagneBike robot is passing over an overhanging gap-type obstacles (a) and climbing a double overhanging step (b). Field validation: the robot is following a circumferential path in a horizontal (c) and inclined (d) pipe.

III. Localization

The second challenge of the MagneBike project was to design a localization and mapping strategy. Because the robot is mainly driven in confined environments out of the user's field of view, the goal is to provide a 3D visualization feedback that helps the human remotely controlling the robot to make correct control decisions. This means providing the 3D position and orientation of the robot (3D localization) in a 3D visualization of the environment (3D mapping). Moreover localization is necessary to precisely locate any defects identified during inspection.

This 3D localization and mapping strategy consists in combining 3D odometry with 3D laser scanning and registration. 3D scanning and scan alignment allow to build 3D maps of the environment, while 3D odometry is used to track the robot position between 3D scans and used as initial guess for the 3D scan registration algorithm. The 3D odometry model assumes slow motion and only requires wheel encoders and a three axis accelerometer. To compensate the lack of angular velocity inputs, the model includes a filter that estimates the local surface curvature. More details about the localization concept can be found in [2].

This video shows an animation of 3D scan alignment as well as the environment reconstruction using 59 scans taken in the steam chest. The resulting map shown in Figure 3 (c) can then be used for inspection mission planning.

IV. Integration and industrialization

System integration is another important result of this work. The MagneBike is actually a small sized system integrating five actuators for locomotion, embedding sensors to control the active locomotion concept as well as localization and mapping sensors. The robot also embeds a single board computer and electronic to control low level tasks involving embedded sensors and direct interactions with the environment or predefined movements. The MagneBike for instance controls behaviors such as the deformation control that avoids robot deformations when driving on irregular surfaces and the control of the stabilizer arms for lateral stabilization (refer to [1] for details).

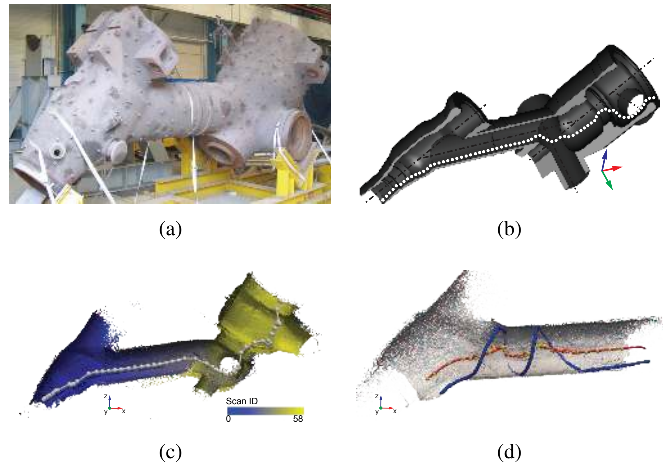

Fig. 3. a) Steam chest environment. b) Approximate CAD model and robot trajectory. c) Environment reconstruction of experiment (b) with 3D scans locations indicated by dots. d) Reconstruction of another experiment where the robot follows a helical trajectory. The trajectory computed by 3D odometry is displayed in blue.

The conceptual prototype has been successfully implemented and evaluated. Given its good performance, the industrial partner decided to invest in the industrialization of the robot. The video finally shows the first version of the industrialized MagneBike robot, also depicted in Figure 1 (b).

V. Conclusion and Outlook

This video presentation provides an overview of a fully integrated mobile robot, that has a very high mobility and integrates sensors for 3D localization and mapping. A future goal of this project is to extend the inspection system to a team of several robots that can independently achieve tasks by cooperation as described in [3].

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