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Design and development of an Inspection Robotic System for indoor applications

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ABSTRACT

The inspection and monitoring of industrial sites, structures, and infrastructure are important issues for their sustainability and further maintenance. Although these tasks are repetitive and time consuming, and some of these environments may be characterized by dust, humidity, or absence of natural light, classical approach relies on large human activities. Automatic or robotic solutions can be considered useful tools for inspection because they can be effective in exploring dangerous or inaccessible sites, at relatively low-cost and reducing the time required for the relief. The development of a paradigmatic system called Inspection Robotic System (IRS) is the main objective of this paper to demonstrate the feasibility of mechatronic solutions for inspection of industrial sites. The development of such systems will be exploited in the form of a tool kit to be flexible and installed on a mobile system, in order to be used for inspection and monitoring, possibly introducing high efficiency, quality and repetitiveness in the related sector. The interoperability of sensors with wireless communication may form a smart sensors tool kit and a smart sensor network with powerful functions to be effectively used for inspection purposes. Moreover, it may constitute a solution for a broad range of scenarios spacing from industrial sites, brownfields, historical sites or sites dangerous or difficult to access by operators. First experimental tests are reported to show the engineering feasibility of the system and interoperability of the mobile hybrid robot equipped with sensors that allow real-time multiple acquisition and storage.

1. Introduction

Inspection, assessment, and maintenance of the industrial sites and existing civil structures and infrastructure are current trends, including large-scale constructs such as plants, tunnels, bridges, roads and pipelines. Robots and automatic systems can perform the inspection process with objective results and high efficiency for those time consuming and repetitive tasks. They can also improve safety by performing inspection in dangerous or unsafe environments instead of the operators. Therefore, manual and (human) visual inspections are being replaced with more precise methods using mechanical, electronic and robotic systems. In addition, data provided by suitable sensors such as images, thermal images, laser can be combined with wireless communication and sensor network to constitute a powerful tool for inspection of industrial sites.

Robotics has been recently applied to tunnel inspection. In fact, tunnels (water supply, metro, railway, road) have increased in both total length and number, and will continue to do so. Robotic solutions were developed and used for inspection of tunnels [1–3] and pipes [4–6], involving visual inspections along with mapping, crack or deformation analysis, by using cameras, ultrasonic sensors, laser sensors, or even being able to perform cleaning or maintenance [7].

Robots were designed and used for search & rescue and planetary exploration, as reported in [8–11]. Service robots can be used to autonomously execute guided inspection tasks in extensive industrial plants. If the equipment is arranged horizontally ground robots can be used, as reported in [12,13], in the case of vessels climbing robots are used [14].

Mobile robots have become a relevant research topic in recent decades and many researchers focus on the development of mobile robots, which are capable of performing tasks such as military operation, security monitoring, exploration, even in dangerous environment. In such situations, robots are mostly working in unstructured environments, which means that the information of the environment where the robot works is unknown. Therefore, in this case the obstacle avoidance is the most important feature for a mobile robot and that is why most researchers focus on the study of the robot with good terrain adaptability. Moreover, such characteristic makes the robot robust and capable to carry in a stable way suitable instrumentation for the given task. Recently, due to the catastrophic events of the earthquakes in center of Italy in 2009 and 2016, the inspection task is the most common and

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requested activity that a mobile robot has to perform in unstructured environment, in unsafe and non-planned events.

Mobile robots are classified as belonging to either legged, or wheeled/tracked, or hybrid mobile systems [15] according to their locomotion systems. Wheeled systems are the most efficient, energy saving and reliable solutions for both ground and climbing mobility, in the latter case the actuation system can be of magnetic or pneumatic type to provide adhesion to the wall to climb. Wheeled robots mainly get the best performances in terms of robust motion on flat surfaces, but they are almost ineffective in overpassing obstacles or on uneven terrain. Tracked systems can partially solve the problem, but they cannot overpass obstacles greater than the track high. Theoretically, legged robots are the solution to all the above-mentioned problems [16], but they have to deal with important issues related to energy consumption, stability and locomotion speed, either if the robot has two, four, six or more legs [17,18]. Hybrid mobile robots move thanks to the combined action of wheels (or tracks) and legs. Examples of such systems are [19–24]. There are four possible combinations of locomotion types that lead to hybrid systems, namely legs-wheels, legs-tracks, wheels-tracks, and legs-wheels-tracks. The three main categories and the four hybrid categories of ground mobile robots are described in [25]. Another classification deals with the combination of locomotion types, i.e. in series or in parallel. In the first type legs (or sub-tracks) provide traction or obstacle avoidance and act in parallel to wheels. In the second type, legs and wheels are coupled in series to operate together. The first type is chosen as design solution for a large number of prototypes and it is used in this context for the proposed system.

Interesting devices have been developed for automatic inspection; systems are equipped with sensors allowing them the exploration of a building in total autonomy, as reported in [26]. In most of cases the sensor suite is devoted to SLAM, automatic path following, obstacle detection and avoidance. Our aim is to test low-cost technologies to monitor and manage sites of interest, trying to significantly reduce the acquisition and maintenance costs and the time needed to the relief.

In addition, inspection and monitoring systems are only apparently tools easy to use and manage, in fact, they hide drawbacks such as high purchase and maintenance costs as well as significant financial commitment related to data management and processing. Those factors greatly influence the wide spreading of those systems, which use is usually limited to high relevance applications, such as military, or in case of disasters like at Fukuhima nuclear plant in 2011 [20].

In order to enhance the use and the spreading of technologies, new solutions have been explored dealing with the concept of robotic and automatic survey using low-cost technology. More specifically, the use of a robotic platform may drastically reduce the time and cost needed for a relief, if compared to a classical approach.

In addition, teleoperation allows the inspection of sites dangerous or difficult to access by human operators. Moreover, the use of low-cost technology both for the mechanical design solution of the mobile robot and the onboard sensors allow the substitution of the IRS in the case of damages or if the robot is lost.

The paper is organized as follows: Section 2 outlines requirements for automatic/robotic inspection and monitoring in industrial environment. A solution is proposed as based on a hybrid mobile robotic platform. Section 3 presents the mechatronic design of the proposed system with suitable sensorization and Section 4 proposes first experimental results for the performance assessment. Finally, conclusions are outlined.

2. Requirements and solutions

In the following, the task requirements and the proposed robotic platform will be illustrated and discussed according to the inspection and monitoring tasks in industrial environment. Nevertheless, the considerations and proposed solutions can be broadly adapted to different types of scenarios.

2.1. Task requirements

The tasks need to accomplish some basic requirements in terms of capabilities, such as mobility, sensorization, communication, and hardware and software reliability. Those issues are detailed in the following for the inspection tasks both in industrial and non-structured environments.

2.1.1. Mobility issue

Urban search & rescue, indoor inspections in industrial environment and outdoor inspections due to planned or catastrophic events, and military intelligence have one need in common, the need of a small sized mobile robot that can travel across a large variety of scenarios. Some of these indoor or outdoor areas to access are not only difficult to reach, but may present also safety and health hazards to human inspectors. Therefore, the development of robots with high mobility and compact design is a priority to cope with these scenarios. Desired capabilities for such robots are: 1) the ability to traverse uneven terrain, slopes, steps, both indoor, in the worst conditions with obstacles such as concrete floors cluttered with debris, unfinished floors such as those found on constructions sites, or obstacles to surpass or circumnavigate, or outdoor in the presence of rugged terrain with stones or plants. Another ability is 2) to fit either through small openings, or overpass wide gaps; 3) the ability to climb up and over vertical steps or overpass obstacles; 4) the ability to travel inside and outside of horizontal, vertical, or diagonal pipes such as electric conduits or water pipes. Those high varieties of areas and circumstances make the mobility issue a prior requirement for such type of mobile robots application. Therefore, the robotic mobile structure has to fulfill the requested mobility issues according to the scenario and the task.

2.1.2. Sensorization

Sensors suite for mobile robots can be classified in two types, namely internal/navigation sensors and external/application sensors. The internal ones give the robot mobility control and navigation capabilities. They may include such devices that allow the robot to be commanded and controlled, i.e. activate and control the motors, and equipment for localization, obstacle detection, position estimation and goal tracking. These sensors are encoders, proximity sensors, GPS, accelerometers, gyroscopes, magnetic compasses, tilt and shock sensors. External sensor suite is related to the specific task, if the inspection/surveillance/search and rescue task is the goal, then sensors such as cameras, thermal cameras, laser, light, temperature, gas, smoke, oxygen, humidity, listening and ultrasound are the most common used sensors to detect the environment in indoor and outdoor environment.

2.1.3. Communication tools

Either wireless or wired-based communication systems can be used for robot localization/navigation and data transmission. Therefore, in indoor environment the condition of signal reception inside a building needs to be checked. In the case of poor or bad reception, a wired-only communication solution has to be considered in order to ensure reliable communication during the inspection.

2.1.4. Hardware and software reliability

It is necessary to specify, at early design stage, if engineers, who are familiar with the design and development of the mobile robot, will operate it; or if novice operators, who are not necessarily capable to perform maintenance to the robot or internal and external sensors suites, will use it. These situations influence both hardware and software reliability. For the first issues, robust hardware has to be designed, built and provided in order to be able to perform a mission without the need of robot maintenance due to breaks or failure circumstances. Referring to the software reliability, it must be easy-to-use and robust, and has to provide almost autonomous data acquisition. In many cases, the engineers are the operators that do the task, but in industrial planned inspection task it would