Chapter

Mechatronics for the Design of Inspection Robotic Systems

Pierluigi Rea and Erika Ottaviano

Abstract

Recent trends show how mobile robots are being widely used in security and inspection tasks. This chapter reports the requirements, characteristics, and development of mobile robotic systems for security and inspection tasks to demonstrate the feasibility of mechatronic solutions for inspection of sites of interest. The development of such systems can be exploited as a modular plug-in kit to be installed on a mobile system, with the aim to be used for inspection and monitoring, introducing high efficiency, quality, and repeatability in the addressed sector. The interoperability of sensors with wireless communication constitutes a smart sensor toolkit and a smart sensor network with powerful functions to be used efficiently for inspection purposes. A tele-operated robot will be taken as case of study; it is controlled by mobile phone and equipped with internal and external sensors, which are efficiently managed by the designed mechatronic control scheme.

Keywords: mechatronics, hybrid leg-wheel locomotion, inspection, interoperability, low-cost monitoring

1. Introduction

Robotics applied to inspection and home security is becoming a reality in recent years. Moreover, with the spread diffusion and popularity of robots in everyday life, their use is enormously increased in recent years [1–4]. Soft computing and artificial intelligence are successfully used for machinery control and robotic and engineering applications [5–7]. The integration of nonlinear system with communication technology has led smart and secure industry and home become reality. Therefore, robots may play an important role in such environments.

In addition, indoor inspection, surveillance, and home security are becoming critical issues at this time to organizing a smart and secure place to live and/or work [8, 9]. Advances in closed-circuit TV (CCTV) technology are turning video surveillance equipment into the most valuable loss prevention tool. Such technology can be considered as a safe and secure tool, which is nowadays available for either industrial, commercial or residential applications. The use of inspection and surveillance systems can alert users for threatening situations worsen, as well as for providing an important record of events, such as inspection of a production plants or buildings, for verification of structural and/or electrical components. However, in most of the conventional systems for surveillance, only fixed cameras and fixed infrared cameras are used. Therefore, drawbacks are related to problems in viewing all video streams at the same time or tracking a moving object through a mobile device due to the object dynamics and limited network bandwidth. In order to overcome these limitations, an increasing number of systems have been developed for automatic inspection; they are equipped with sensors allowing the exploration of a building, as reported in [10].

Inspection and monitoring systems are apparently the only tools that are 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. In addition, interoperability and integration with other devices could be a problem; those factors may greatly influence the wide spreading of those systems. In order to enhance the use of these technologies, new solutions have been explored dealing with the concept of robotic and automatic survey using low-cost technology [11]. 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. Moreover, the use of a low-cost technology, both for the mechanical design of the mobile robot and the onboard sensors, allows the wide spreading of the robotic system and substitution in the case of damages or if the robot is lost. In addition, the developed technology may allow the interoperability of the system and integration in the industrial environment by taking advantage of Industry 4.0.

2. Requirements and solutions for surveillance and inspection robotic systems within Industry 4.0

Surveillance and automatic inspection tasks require a careful analysis to identify basic requirements and appropriate solutions, as it is represented schematically in **Figure 1**. A first basic requirement is related to the mobility issue, which deals with the site to inspect, that is, buildings, industrial plants, or other indoor environment. Indoor and outdoor inspections often require different solutions, either ground or aerial ones. They have in common the need to have a relatively small sized mobile robot that can travel across a large variety of scenarios.

Mobile robots can be classified according to their type of locomotion. Walking systems are well suited for unstructured environment because they can ensure stability and adaptability to a wide range of situations, but they are mechanically

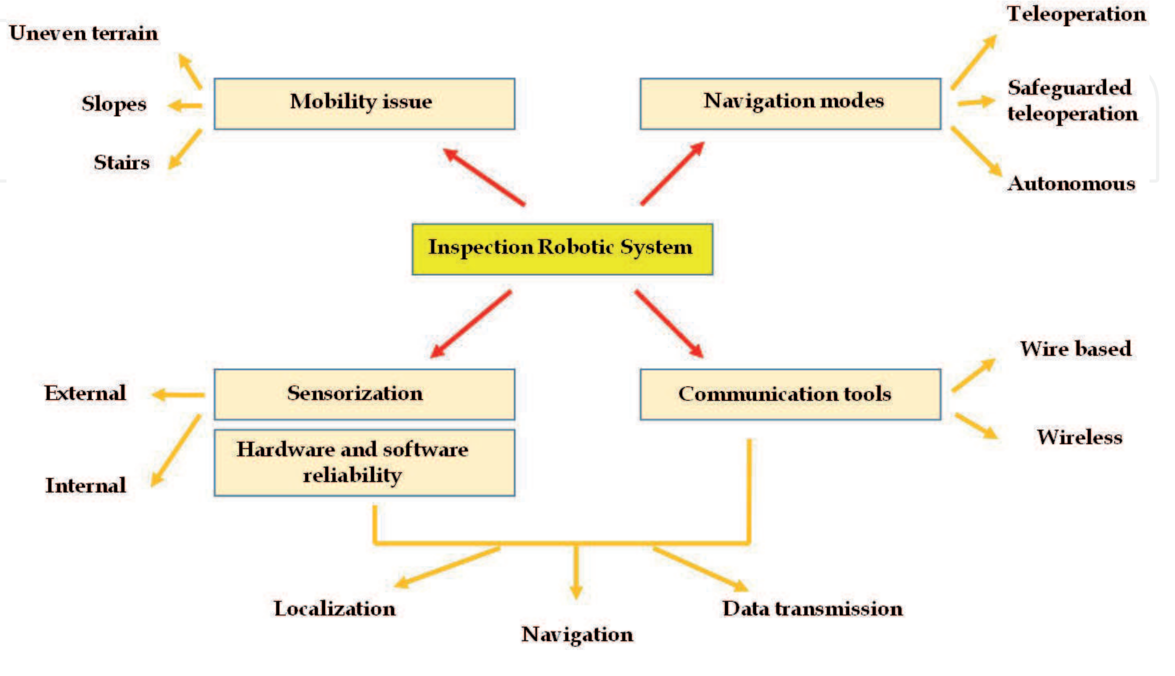

Figure 1.
Flowchart of the main requirements and solutions for a mechatronic design of inspection robotic systems.

complex requiring high power and control efforts [12]. Wheeled locomotion instead is the most efficient solution on flat surfaces [13]. In fact, wheeled or tracked robots are the optimal solution for well-structured environment and quite regular terrain. In off-road, their mobility is often very limited and highly depends on the type of environment and the dimension of the obstacles. Hybrid mobile robots have been developed to combine advantages of legged- and wheeled-/tracked-locomotion types; therefore, lately they are preferred for a large variety of scenarios and applications. Very often the mechanisms used for the locomotion (legs, articulated wheels) should be synthetized ad hoc [14, 15]. A proper model of the mechanical system has to be developed for programming and communication issues [16, 17].

A classification of three types can be made referring to navigation modes, namely, pure teleoperation, safeguarded teleoperation, and autonomous navigation, according to the task and overall budget. The choice depends on the application and the environment. The sensorization is strictly related to the navigation type and the level of sophistication of the inspection. It is possible to classify sensors as internal and external ones. The internal ones give the robot mobility control and navigation capabilities. They can be proximity sensors, encoders, GPS, accelerometers, gyroscopes, magnetic compasses, and tilt and shock sensors. External sensors are related to a specific task; for the inspection and surveillance application, the sensors considered can be cameras, thermal cameras, laser, light, temperature, gas, smoke, oxygen, humidity, sound, and ultrasound. Hardware and software reliability deals with the end user/application of the robot. In fact, this issue has to be set at very early stage of the design process since it is related to operation, maintenance, failure prevention, and intervention.

Communication tools are essential for localization, navigation, or data transmission [16, 17]. In addition to wired and wireless communication, a great challenge is the interoperability with any automatic and robotic system with other devices, such as home automation and security system in industrial plants according to Industry 4.0. This issue is specifically related to the application for surveillance, inspection, and maintenance for structures and infrastructures and in industrial environment, also related to sustainability [18, 19]. Recently, the term Industry 5.0 has been introduced in 2015; comparing with Industry 4.0, which is being considered as the latest

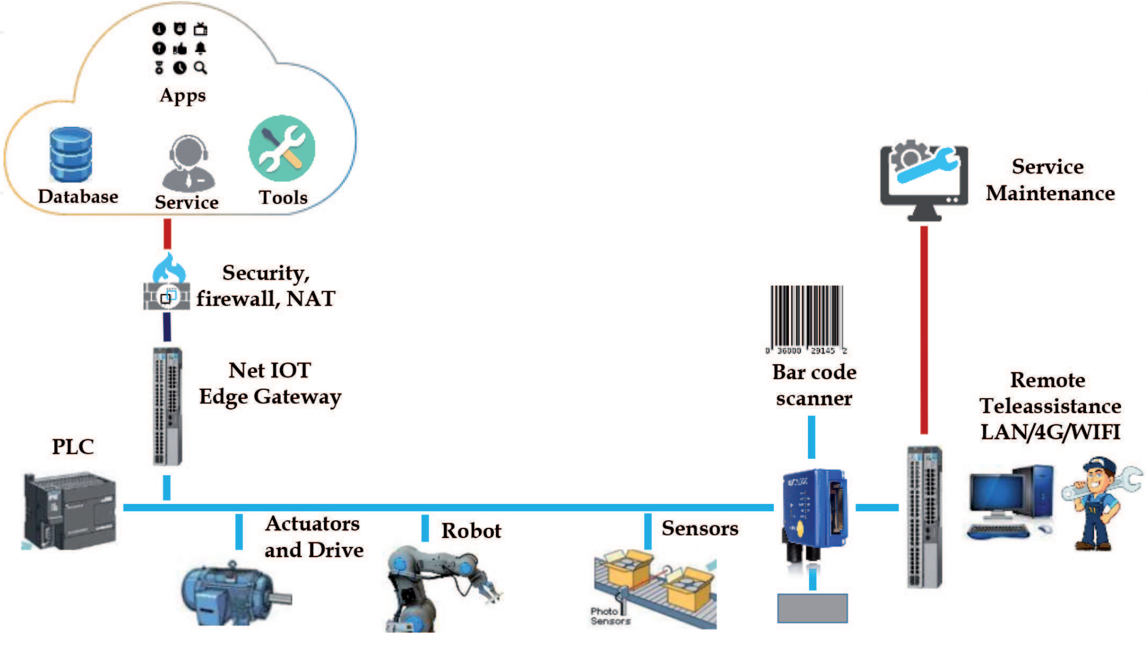

Figure 2.
A scheme for the levels in Industry 4.0 organization and interoperability of robotic systems in industrial environment.

industrial revolution, it can be considered a systemic transformation that includes impact on civil society, governance structures, and human identity in addition to solely economic/manufacturing ramifications, the Industry 5.0 founders prefer to speak about next step in evolution.

The fourth industrial revolution has been applied to significant technological developments several times over the last 75 years and is up for an academic debate. Industry 4.0, on the other hand, focuses on manufacturing specifically in the current context and thus is separate from the fourth industrial revolution in terms of scope. It is very interesting to analyze the significant trimming of the time needed to go from one revolution to the next one. From this regard, the introduction of Industry 5.0 just 4 years after the start of Industry 4.0 is not an exception, but a winner (**Figure 2**).

3. Mechatronic design of inspection robotic system

The mechatronic design of an inspection robotic system can be schematically composed by two main parts: one is related to the robot mobility and operation modes and the other one is responsible to manage the external sensor kit, specifically made according to the application. **Figure 3** shows the mechatronic architecture of the THROO system, proposed by Rea and Ottaviano [10] and used here as paradigmatic example.

According to the scheme reported in **Figure 3**, a tablet in (1) is used for the robot motion control and navigation, taking advantage of the two sliders represented in the zoomed view in (7). The Dension WiRC software is used for programming. The USB WiFi router type is TP-Link Model TL-WN821N, and it is represented in (2) and allows the tablet to access and connect to the WIRC hardware. The webcam (3) is the Logitech U0024 type. The Dension WiRC hardware (4), with four digital inputs, four digital outputs, and eight channels, is used to control the servomotors of the robot. The hardware in (4) is connected to Arduino board (5) and gives the command to the robot's actuators via relay (6). The target (8) is displayed on the tablet.

The overall mechatronic system architecture for the robot navigation is given in (9). For the proposed application (indoor survey) teleoperation mode is used;

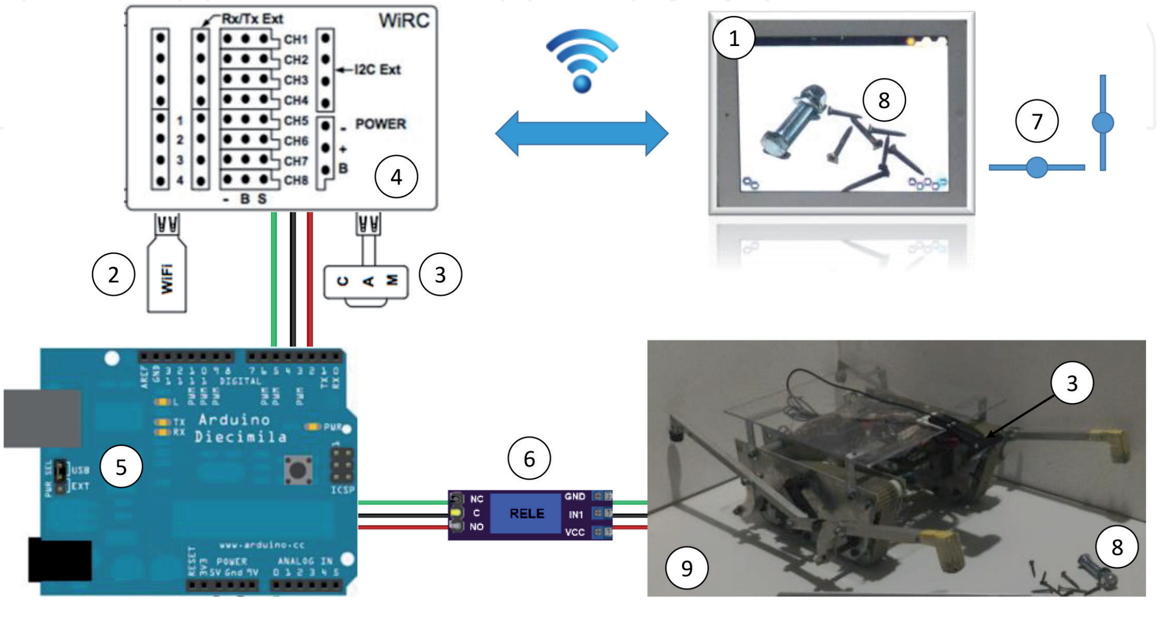

Figure 3.
Mechatronic architecture of the control for the THROO robot.

DOI: http://dx.doi.org/10.5772/intechopen.88489

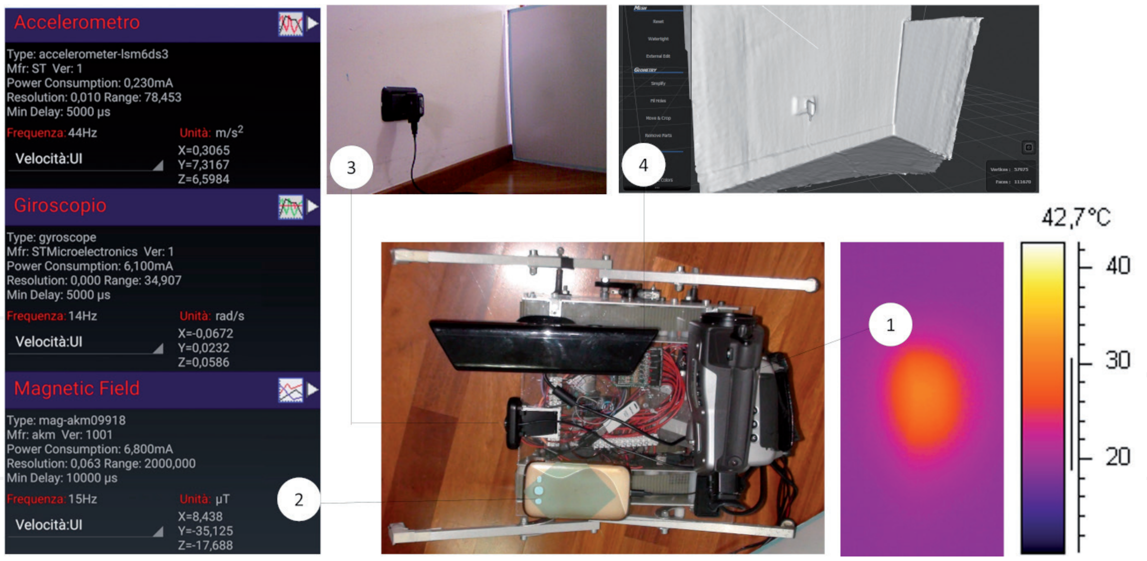

Figure 4.
Sensor installation on the inspection robot.

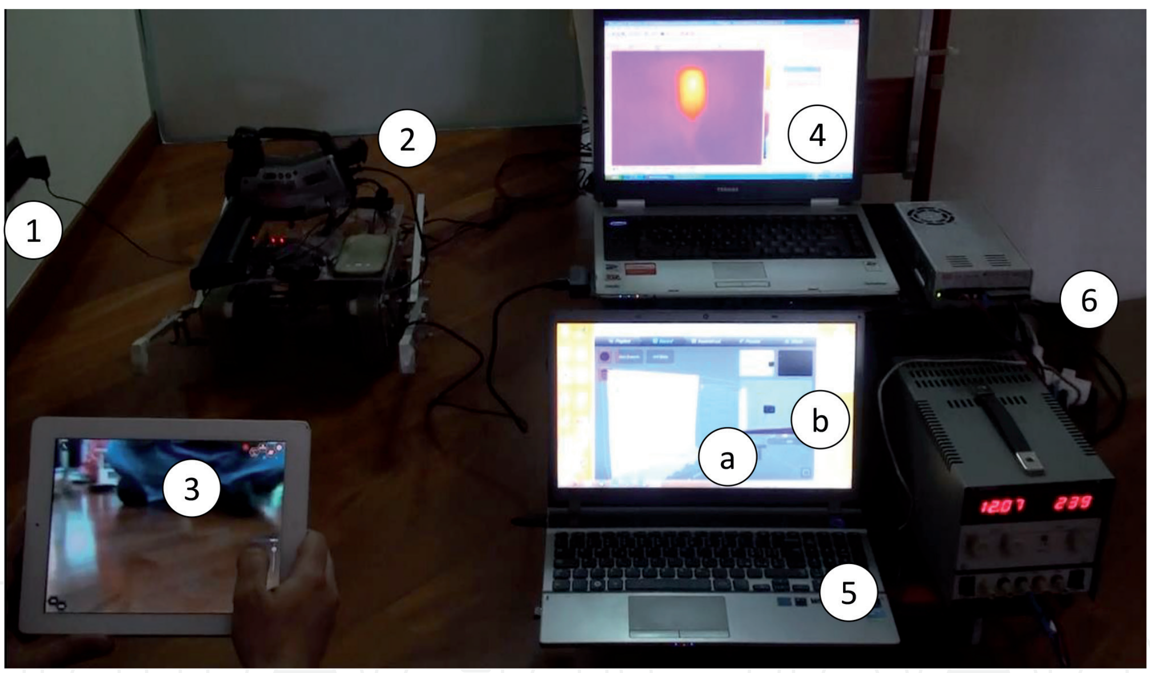

Figure 5.
Overview of the proposed mechatronic/robotic system.

therefore, when the robot in **Figure 4** moves, the internal sensor suite is used to help the user to understand the environment and guide the robot to the path or a close target. In particular, in **Figure 4**, label (2) is for the electronic board equipped with accelerometer, gravity and gyroscope sensors, GPS sensor, magnetic field, and acceleration sensors. The front camera view for navigation is displayed as (3). External sensors are used for inspection and monitoring tasks. More specifically, in **Figure 4**, label (1) is used for the thermal infrared camera FLIR ThermaCAM S40, and the 3D scan is the Xbox Kinect shown in (4), provided with an infrared sensor and two additional micro cameras.

Examples and applications of industrial and nonindustrial applications are reported in [20, 21]. An overall layout for the system is given in **Figure 5**, in which the main components may be recognized, mainly the robot in (2) with external and internal sensors, operating (3) and monitoring (5) (6) systems, and the power

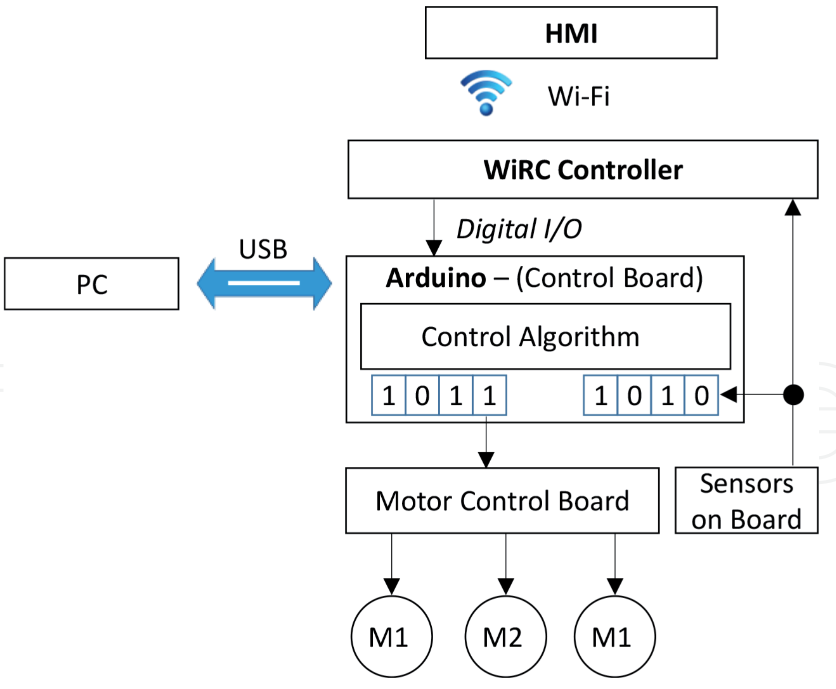

Figure 6.
A scheme for the control architecture.

supply (6); label (1) represents the target. **Figure 6** shows the control architecture to operate the robot and a representation of the interoperation with the equipment onboard.

The use of this kind of control system solution offers several advantages, which can be summarized as follows:

1. Low cost—Arduino boards are relatively low cost, if compared to other microcontroller platforms. They may enable diffusion and affordable cost of the overall system.

2. The Python software runs on Windows, Macintosh OS X, and Linux operating systems. Most microcontroller systems are limited to Windows.

3. Simple, clear programming environment—the programming environment is easy to use for beginners, yet flexible enough for advanced users to take advantage of as well.

4. Open-source and extensible software—the software is made available as open source tools, suitable for extension by experienced programmers. The language can be expanded through C++ libraries.

5. Open-source and extensible hardware—the plans for the modules are published under a Creative Commons license, so experienced circuit designers can make their own version of the module, extending it and improving it. Even relatively inexperienced users can build the breadboard version of the module in order to understand how it works and save money.

CANopen is a CAN-based communication system. It comprises higher-layer protocols and profile specifications. CANopen has been developed as a standardized embedded network with highly flexible configuration capabilities. It was designed originally for motion-oriented machine control systems, such as handling systems.

Parameter description	**Specification**		
Robot system			
Hybrid mobile robot THROO	Size (L × H × W)	300 (550) × 140 × 400 mm	
	Mass	4.5 kg no batteries	
	Max speed	Up to 0.5 m/s	
	Actuation	DC 24 V 12 Nm 24 W	
	DOFs	2 (track), 1 (legs)	
	Max step size	100 mm	
Internal sensors	*Range*	*Resolution*	*Power*
PSH accelerometer (Intel Inc.)	0–39.227	0.01 (0.024%)	0.006 mA
PSH gyroscope sensor (Intel Inc.)	0–34.907	0.002 (0.005%)	6.1 mA
PSH gravity sensor (Intel Inc.)	0–19.613	0.005 (0.024%)	0.006 mA
PSH magn. field sensor (Intel Inc.)	0–800	0.5 (0.062%)	0.1 mA
PSH lin. accel. sensor (Intel Inc.)	0–19.613	0.005 (0.024%)	0.006 mA
External sensors	*Model*		
Thermal camera (FLIR)	ThermaCAM S40		
Front camera (Logitech)	U0024 type		
3D scan (Xbox)	Kinect		
Communication			
USB WiFi router	TP-Link Model TL-WN821N		
Control station			
No. monitors	2		
No. computers/CPU	2		

Table 1.
System specifications.

Today, it is used in various application fields, such as medical equipment, off-road vehicles, maritime electronics, railway applications, or building automation. In order to obtain this low-cost control system, the advantages of using Arduino with CANopen for data transmission have been combined. This was possible using a PiCAN 2 breadboard interface card that allows Raspberry to send commands via CANopen.

Table 1 summarizes the main features of the proposed system. The integration of sensors and its management has been a subject of research activity in different domains [3, 4, 22–24]. An industrial network laboratory prototype has been proposed by Leão et al. [25] in which several kits have been implemented.

4. Cases of study

The THROO system has been proposed here as a paradigmatic example of a mechatronic solution for the design. Applications reported here refer to indoor surveys. **Figure 7** shows the robot operation during an indoor inspection. In particular, thermal detection of an electrical component is carried out. The interoperability of the sensors onboard with navigation sensorization is managed by the control board and the WiRC controller.

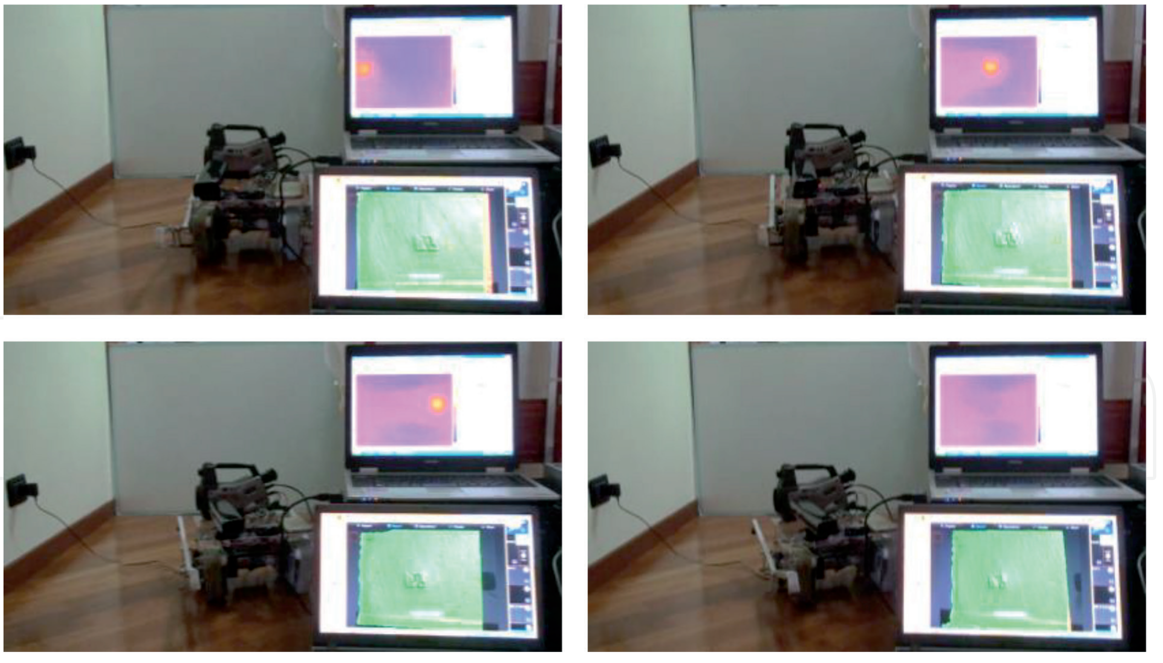

Figure 7.
Photo sequence of an experimental test of data acquisition.

Figure 8.
Photo sequence of data acquisition during a survey.

Figure 8 shows an indoor survey in which an indoor wall element made of limestone rock is analyzed, as reported in [11]. All the acquired data is monitored on two screens as shown in **Figure 8** and stored in a PC for further analysis and reconstruction.

5. Conclusion

In this chapter, we have proposed the main requirements and related items for a mechatronic design of an inspection and surveillance robotic system. The mechatronics and control scheme proposed here might constitute a solution for a broad range of scenarios spacing from home security and inspection of industrial sites, brownfields, historical sites, or sites dangerous or difficult to access by operators. As a paradigmatic example, a hybrid robot is presented here, and 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. The robot equipment is composed by external and internal sensors, for example, gyroscope, accelerometer, inclinometer, thermal camera, and 3D motion capture system.

Conflict of interest

The authors declare no conflict of interest.

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