Application of an Inspection Robot Composed by Collaborative Terrestrial and Aerial Modules for an Operation in Agriculture

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Abstract. FREEDOM robot has been developed for exploring dangerous or inaccessible sites by human operators, either from the ground and/or from the air, in urban environment, due to planned or emergency response events. The system, composed by ground and aerial modules, it is based on the design concept of taking advantage of both systems sharing design philosophy and management. One of the main design issue is the possibility of extending the inspection capability by providing power supply from the ground module to the flying module. In this contribution, system basic features and the application to agriculture are proposed.

Keywords: Mobile robot · Flying robot · Mechatronics · Precision farming · Agriculture

1 Introduction

In recent years, a large number of applications deals with inspection, control and monitoring of industrial sites and areas of interest due to planned or emergency response operations. In this context, either aerial (UAV), or ground (mobile robot) solutions are adopted, depending to the specific applications [1–4]. More specifically, the above-mentioned solutions have become attractive for missions where human presence is dangerous or difficult. However, an integration between these two types of system has not been yet developed and it represents a challenging task.

Referring to the ground module, the type of locomotion should be selected in order to achieve stability, flexibility, maneuverability while being easily controllable and of a low cost. Several types of locomotion systems were proposed in literature, they are usually classified as wheeled/tracked [5], legged [6], or a combination of the two being

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hybrid solutions [7, 8]. In particular, the latter represents a good compromise exploiting the terrain adaptability of legs in rough terrain and simpler control, as well as high speed, thanks to wheels/track. Taking advantage of these features, hybrid mobile robots have been successfully used in very hard environment, such as Mars exploration [9], in the damaged Fukushima nuclear plant after the 2011 Tōhoku earthquake and tsunami [10] or for mechatronic surveys [11].

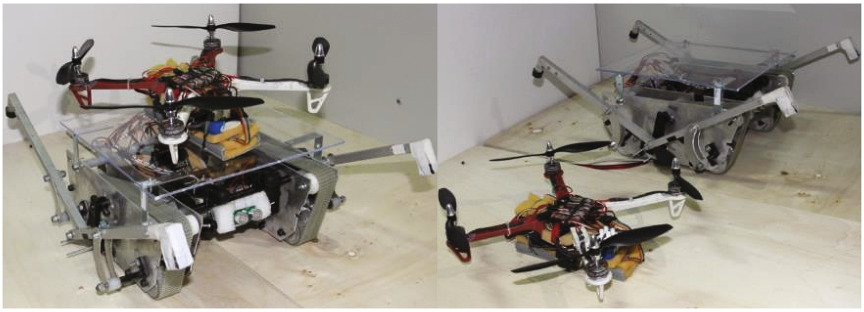
Modern problems are the coordination among different type of drones, and multi-robot cooperation. These issues offer some challenges as for example, the solution of problems related to perception, decision and action [12]. In the literature, a large amount of works related to multi-robot systems can also be found in [13–16].

In recent years, many expectations are growing regarding applications of the unmanned aerial vehicles (UAVs) in agriculture [17]. Recently, many works address this issue [18–24]. In this field, it can be of interest to consider cooperating agents of different types, as for example, aerial and ground ones. Regarding the aerial module, it may consist in a multi-rotorcraft, which is relatively new with respect to the concept of fixed wing flying. Multi-rotors have been widely accepted thanks to their potentialities, widespread from entertainment to the inspection, surveillance and 3D reconstruction as flying supporters for digital video/photography equipment. By the way, the potential use of rotorcraft is still limited by their short range.

Referring to agriculture, the state of the art of aerial measurement is represented by the so-called multi-spectral photogrammetry, which aims to provide an efficient method of evaluation for some parameters in the culture. However, the calibration of the method requires extensive research, and great effort is still needed to obtain a valid methodology [25]. Several measurements must be carried on by reaching the same position in different times of the day in order to evaluate the effect of solar illumination over the acquired images [26]. The inherent short range of a typical multi rotorcraft powered exclusively by batteries then limits each of these activities. The cooperation of a ground crawler, able to travel for long distances and carry heavy loads, power supply included, with an aerial multi-rotor, able to fly for a limited time, represents an excellent synergy providing an efficient system. Main characteristics of the system are the ability to travel within the operational site and, therefore, to launch the copter to perform air and land patrolling and precise aerial monitoring. The flying unit can therefore land/dock over the ground crawler to be secured for transportation, while its battery being reloaded by the rover power unit.

2 Description of the System

The proposed system is composed by a ground module and aerial module, which have been designed and built sharing the same design philosophy and control architecture. A first prototype is shown in Fig. 1 being both modules described in detail in the following Sub-Sections.



a) b)

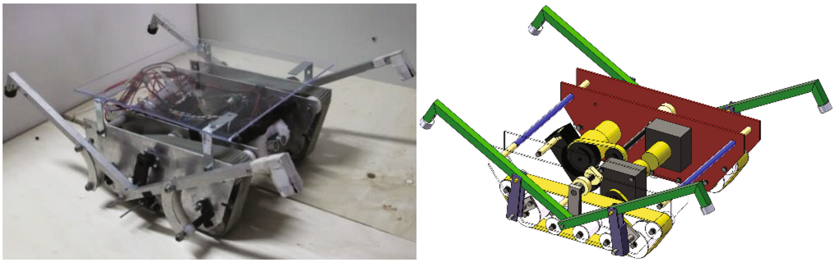
Fig. 1. The proposed ground/aerial robot composed by the two modules: (a) in a combined operation mode; (b) the ground and aerial modules for an in parallel operation.

3 Ground Module

The ground module is shown in Figs. 2(a) and (b); it is composed by the hybrid rover THROO, which has been designed and built at the University of Cassino and Southern Lazio for inspection of indoor and outdoor environments [27]. The basic design and features are mainly related to the presence of both tracks and legs for an efficient locomotion having the ability of overcoming obstacles. The ground module has three DOFs, two of them are used for the track giving holonomic robot for the motion on flat terrain. An additional actuator is used for the four legs, which are arranged as front and rear couples, sharing the same crack and providing mirror trajectories of the leg end-points, as shown in the scheme of Fig. 2(b).

Characteristics of the built prototype are the following. The size is 550 × 400 200 mm, all mechanical components are made of aluminum and actuation and transmission systems are of commercial type. Details on the mechanics are given in [27].

The overall mass of the prototype is 4.5 kg (batteries not included). It is worth to note that its length and high vary according to the legs' configuration, here maximum values are given. Two DC motors for the track with following features compose the actuation system: power supply of 24 V, max torque of 5 Nm, nominal power of 3.9 W. The motor used to actuate the legs has a power supply of 24 V, max torque of 12 Nm,



a) b)

Fig. 2. The ground module: (a) the prototype; (b) the mechanical design.

nominal power of 24 W. A scheme for the mechanical design is given in Fig. 2(b). A tensioning track system will be developed as based on the solution in [28]. Two operation modes are provided, a rover-like motion on flat or uneven terrain, and rover walking aided motion in the presence of obstacles that are equal to or greater than the dimension of the track. In particular, the presence of the legs gives the ability to the rover to withstand overturning up to 60°.

4 Aerial Module

The flying module shown in Fig. 3 consists in a four-propeller multirotor, officially designated as Remote Easy Stackable Quadrotor (RESQ) - named “Quattrino” by the designer R. Grassi. It has been developed and built as a test bench for the original development of the control software and for assessing the procedures of docking and undocking from the crawler. The simple architecture of the quadrotor, with two couples of counter-rotating propellers, is compensated by a not negligible effort in the development of the control software: compared with the bigger sized rotorcraft operations it is more difficult to achieve a steady flight and to obtain a secure docking. The first prototype of the rotorcraft is remotely controlled, with an augmented stability algorithm that combines the inputs from the operator with the readings from the inertial measurement unit, housed onboard.

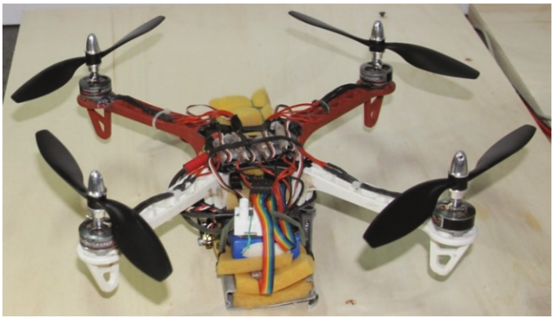


Fig. 3. The aerial module.

The prototype size of the rotorcraft is 300 × 300 mm, equipped with 200 mm propellers, with a mass of 0.8 kg. It has a flying endurance, performing slow maneuvers and aerial reconnaissance, of half an hour, and it requires a current of 10 A to remain in hovering.

5 Energy Management Unit

Both the aerial and ground modules relies on batteries to store the necessary energy for performing their tasks. The aerial module is equipped with a 4 Ah Lithium-Polymer battery with fast charge capability up to 20 A, and the ground module is powered, at the actual stage of the development, with a SLA (Sealed Lead Acid) battery with 20 Ah capacity. The system is designed to allow an energy exchange between the two units when the quad-rotor is docked on the ground crawler.

More specifically, the first designed prototype allows, through a low current connection, to perform a topping charge keeping the quad-rotor battery at its top level while travelling detaching the connection when taking off. The final aim of the project is the design of a recharging system, which will refuel the quad-rotor, allowing more than one flight per mission.

6 Remote Control and Data Transmission

Figure 4 shows the mechatronic architecture for control of the ground module. According reported scheme, it can be operated via tablet in (1) having the software installed onboard. The DENSION WIRC software allows to turn on and off digital inputs and outputs, and move the robot, thanks to the two sliders indicated with (7) in Fig. 4. The USB Wi-Fi router type TP-LINK Model TL-WR 340 G in (2) allows the tablet to connect to the WIRC hardware. The webcam CAM in (3) is the Logitech V-U 0024. The WIRC hardware in (4) is connected to and command the Arduino board (5), which drives via relay (6) the robot's actuators. The target (8) is displayed on the tablet; (9) represents the overall mechatronic system architecture.

The rotorcraft remote control requires a constant and stable data transmission of approximately 3 Kbit/s upstream for the HMI controls, and 30 Kbit/s downstream for the telemetry signal, plus an A/V downlink for the monitoring camera. Several strategies for the remote control signal transmission have been analyzed and the right choice depends on the environment where the robot will need to operate; the frequency assignments and the power limitations stated by the regulations must cope, as for

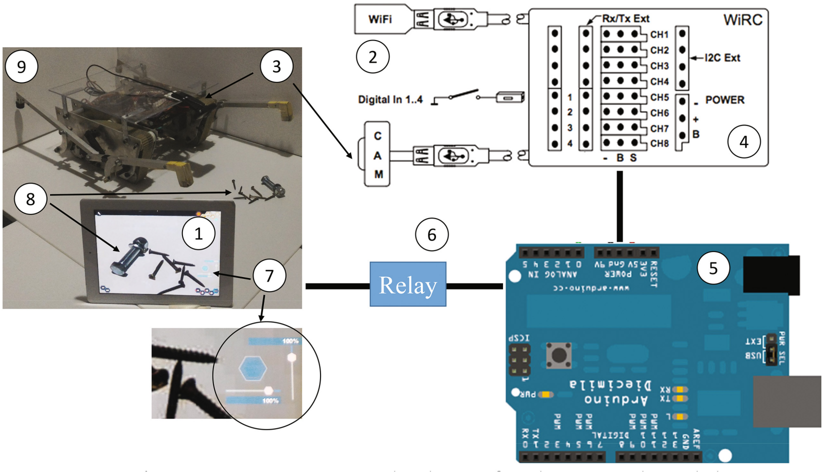


Fig. 4. Remote control scheme for the ground module.

example, with the necessity of penetrating concrete buildings and structures. The integration between the units will be studied in order to let the ground module, if needed, to act as a signal repeater for the aerial link and multiple paths for control, telemetry and AV links can be implemented.

An innovative unified control architecture is currently on development based on the use of Xbee modules and a dedicated microprocessor board such as Teensy 3 or similar with the aim of relaying the signals between ground control, ground crawler and aerial module creating a sort of network, called MESH, which provides relaying, and redundancy of control signals. The multicopter will benefit from its immediate access through the RF link because the hardware is completely built from the scratch and reconfigurable. An interface is currently on design to allow a similar data exchange with the ground crawler.

For the integration of the control operations, an architecture similar to what has been developed within the CLEM EU project [29] is considered as based on a Cloud service from which the simultaneous access is made possible to operate the ground and aerial modules acting together or in parallel (Fig. 5).

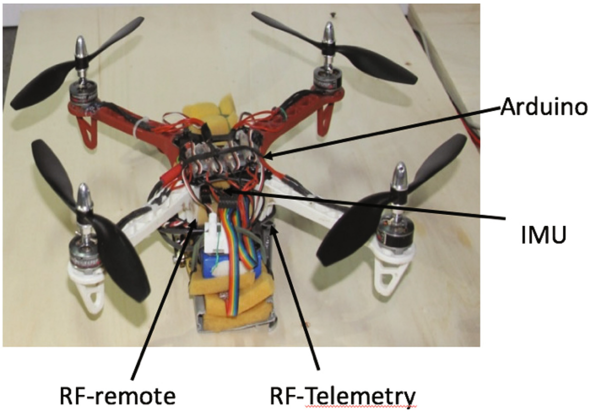


Fig. 5. Remote control scheme for the aerial module.

7 Proposed Design for an Application in Agriculture

Precision agriculture means agriculture assisted by new technologies. In the economies of Western countries where agriculture is supported by government policies, the trend passed to maximize agricultural production has led to severe environmental impacts. In the immediate future, the agricultural focus has shifted from maximizing production to sustainability. The objective of the proposed in its configuration system for agricultural use is still maximizing product quality constantly trade off with respect for the environment. The proposed system stands as the innovative application of technology to agriculture: satellite positioning, active remote sensing and special sensors installed on the aircraft. FREEDOM operational capabilities benefit from the great “virtual” flight range offered by the combined system crawler-copter. In fact, the aircraft will take off only during the real precision farming operation, while being transported towards the operational areas by the crawler. This way it will be possible to operate a recharging of the batteries during transfer obtaining a double advantage in terms of efficiency.

8 Conclusion

A robot composed by collaborative ground and aerial modules is proposed to integrate and exploit the advantages of both systems. The robot is intended to be used for multi-agent missions, like for example, search and rescue applications. In this contribution, issues, requirements, and modifications related to the application in agriculture have been reported to design a second version of the prototype.

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