



User Manual

Unmanned Robotic Vehicles

30th September 2020

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1 Intended Audience

An output of the INDIRES project is user documentation for each of the products produced during the project. However, the status of the various products differs and, for this reason, the intended audience for the *User Documentation* will be different for each product. It is necessary, therefore, to indicate the type of user who will benefit from this particular *User Document*.

The robotic vehicles described here were fully prototyped and tested in a mine-like environment. As such, the information provided in this *User Document* could be utilised by end users who have a need for the exact functionality provided by the INDIRES prototypes. Such users can consider the instructions on how to use the robotic equipment as definitive.

The prototypes contain fully working software to solve the novel problem of mapping and navigating in a highly unstructured environment such as a mine following an incident. However, the basic hardware is based on commercially available robotic platforms, suitably modified to meet the needs of working together as a team in a rescue scenario. In that sense, they could be considered as proofs-of-concept, and could benefit from further development of the robotic platforms to be better suited to the extreme mine environment. For this reason, other potential users of the information provided here are developers who would welcome the opportunity to further adapt this equipment to make it more immune from harsh environments.

End users or developers who want to know more, and perhaps to discuss possible collaborative opportunities, are referred to *Section 7*.

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2 Overview

A team of robotic vehicles has been developed for exploring an incident area before deciding whether it is safe to dispatch human rescue personnel into that region. The robots in the team each have different capabilities to allow an area to be surveyed in a much more efficient way than could be achieved using only one type of robot. The team comprise the following robotic vehicles.

2.1 Ground Robot

The ground robot is powerful tracked robot with a good autonomy and payload capacity. For these reasons, the vehicle has a twofold function; as the ground robot as part of the team, and as the Vehicle Processing Hub, carrying the other two robots, plus the hardware for processing and communication, to the incident area.

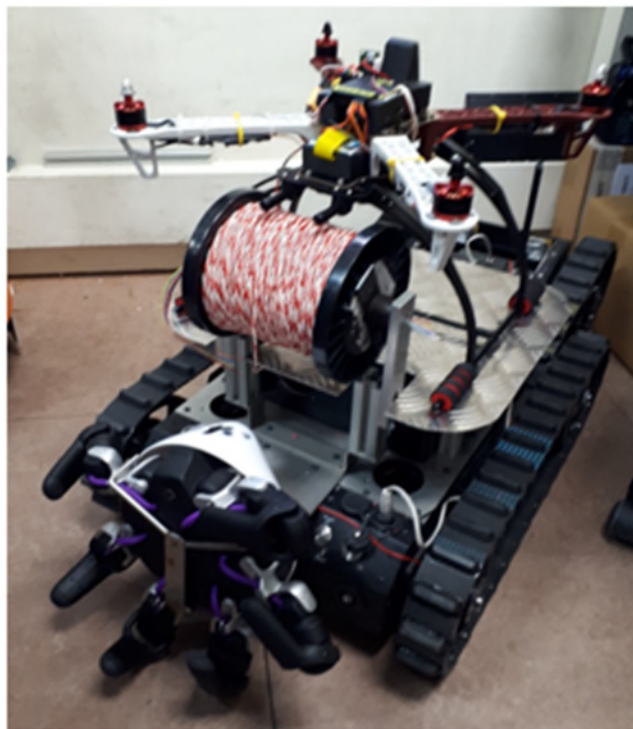


Figure 1 – Ground Robot with Aerial and Spider Robots On-board

2.2 Aerial Robot

The aerial vehicle, otherwise known as a drone, is a low-cost quadcopter of medium-small size. It allows large areas to be covered in a short time. However, the autonomy and the payload capacity are very limited.



Figure 2 – Aerial Robot

2.3 Spider Robot

Small crawler robots can cover only small areas of terrain, but they can access small cavities and holes that are inaccessible to other types of robot. The type developed is small spider-like robot with six legs.



Figure 3 – Spider Robot

2.4 General Comment

The necessary instructions for interacting with the robotic team are provided in this document. Most of the instructions on how to use the robotic equipment are definitive. However, there are parts of the system that are still proof-of-concept and therefore, some minor changes in the operative steps could arise if and when they are developed further.

3 Ground Robot

The functioning of the ground robot is quite straightforward. It also carries all the hardware for communicating with the other vehicles and with the control station.

3.1 Powering

The robot has three buttons on the rear part (see *Figure 4*). To power on the ground robot, you should press these buttons in the following order:

1. **Power Button** This initialises the electronic components mounted on the robot. For instance, the router and modem for communication. The small light below the button (on the right side) should turn on.
2. **Motor Power** This enables the motors. The left light below the power button should be illuminated when the motor power is turned on.
3. **PCs Power** This must be pressed to turn on the two computers in the robot.

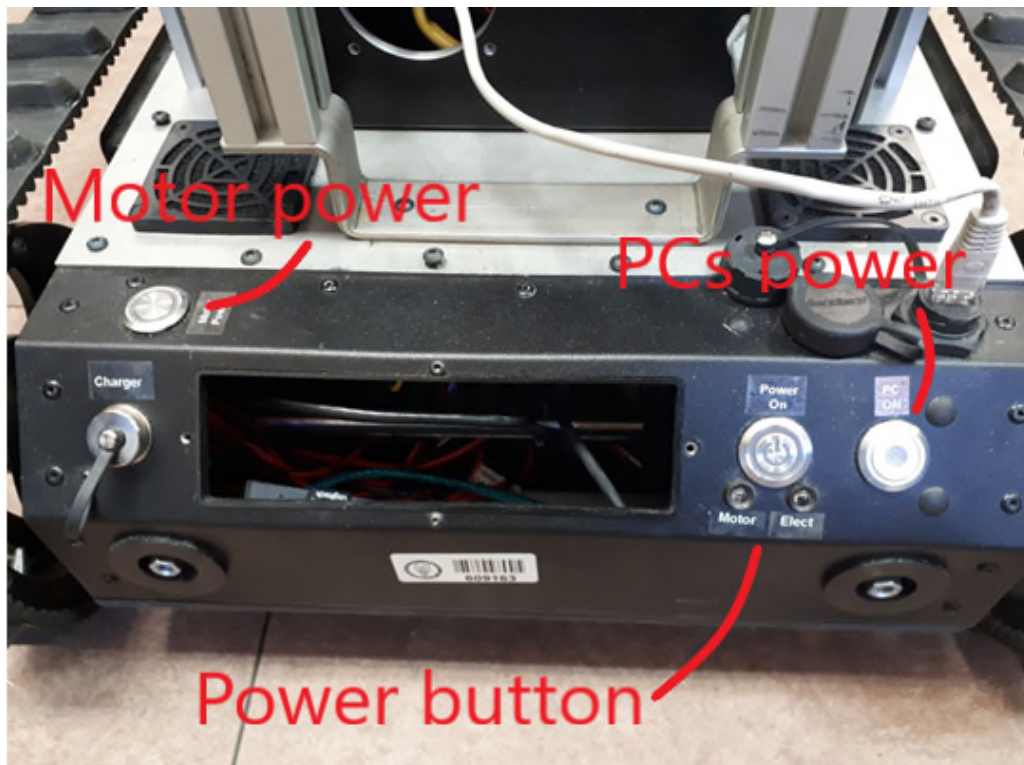


Figure 4 – Powering Buttons of the Ground Robot

To turn off the robot, the order must be the opposite. First, the computers must be switched off. To do that, press the PCs Power button for at least five seconds. Then, press the Motor Power, and finally, press the Power button.

3.2 Charging

The system is powered by two 18V 12Ah Li-ion batteries with a burst current capability of 60A. One of the batteries powers the electronic components, and the other powers the motor drivers.

To charge the batteries carry out the following steps:

1. Plug the charger (see *Figure 5*) into an AC power wall outlet.
2. Connect the long power cable to the external power connector on the rear part of the ground robot. The connector is indicated with the tag “charger”.
3. Turn on the charger by pressing the red power button on the back of the charger box.

From that moment, the system will start charging the batteries and the robot is powered using the external power supply.



Figure 5 – Ground Robot Charger

The batteries can be charged with the robot powered. That means that the robot can move while being charged, so long as the maximum motor power current capability of 13.4A is not exceeded. Both power supplies are regulated to 24V, which is more than the batteries can provide. These values can be used to understand if the robot is being powered by batteries or by the external power supply.

On the charger there are four status LEDs on the front (see right image of *Figure 5*). The ones on the top show if the motor and electronic power supplies are working. The ones on the bottom show the charging state of the motor and electronic batteries. If the LED is red the battery is being charged, if green the batteries are fully charged.

To unplug the external power supply, just disconnect the power cable from the external power connector of the robot if the robot is not powered. Never disconnect the main switch of the external power supply while the robot is being powered. This procedure will make the computers disconnect. Therefore, the robot must be shut down completely before removing the charger.

3.3 Functioning

On start-up, both computers initialize all the processes required to operate with the robot:

- ROS drivers for control of the motors and odometry computation,
- ROS drivers for the set of sensors,
- ROS system for autonomous navigation and exploration,
- network configuration and communication,
- http server for handling the website for control and monitoring.

The setup of all the processes takes at least 30 seconds. After that time, you can connect to the control and monitoring website using a web browser on any computer connected to the communication network. This is described in *Section 0*.

The only service that is not launched on start-up is the mapping system. In the current system, an expert user must access one of the computers by SSH protocol and to launch the mapping system by means of commands in a terminal. To avoid that, two options could be implemented so that the user only needs to open the control and monitoring website:

1. To launch the mapping service on the start-up too. However, that means that the robot is building an online map from the moment that it is turned on. That is not desirable in situations in which a robot must be firstly teleoperated to the area of interest and a map of the travel to that area is not required.
2. A second option would be to include a button to start/stop the mapping system in the control and monitoring website. This way, the user can decide the area that is going to be mapped.

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4 Aerial Vehicle

Complying with the ATEX requirements is especially complex in the case of the aerial vehicle. We explain here the operating instructions of the “proof-of-concept” aerial vehicle. These instructions might change, in the part related to the hardware (buttons, connectors, wires, etc.), if a prototype closer to the ATEX requirements is used.

4.1 Powering

The “proof-of-concept” quadcopter is powered by connecting the battery connector to the drone as explained in *Figure 6*. A proper enclosure and a switch should be installed for safety reasons instead of using the current system.

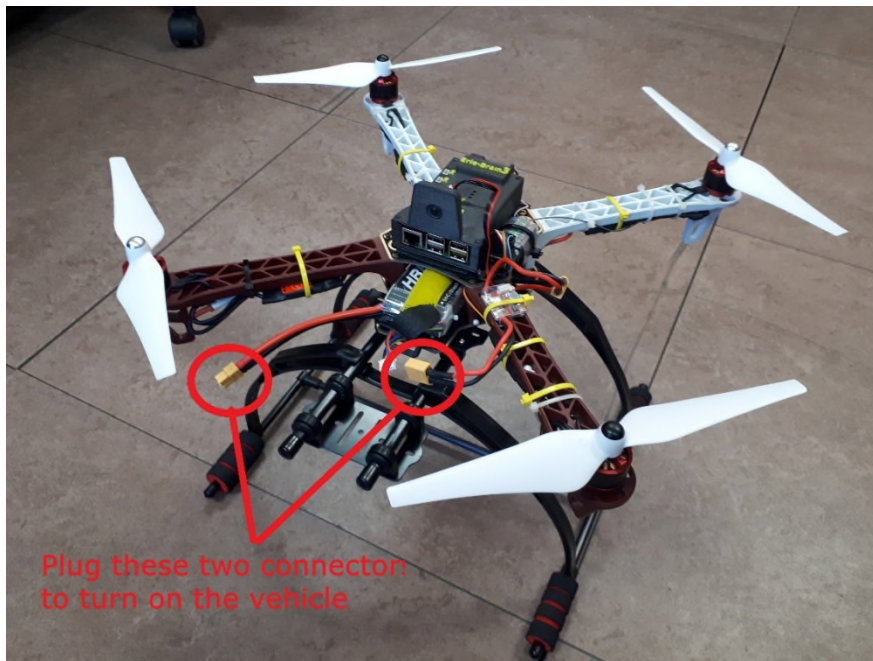


Figure 6 – Turning on the Aerial Vehicle

When the drone is powered on it performs some initial calibrations. During this process, the drone should stay still in a steady and straight position. Its position on top of the ground robot is acceptable during this period, but the ground robot must also stay still and be in a non-inclined position. This process can last around 40 seconds.

4.2 Charging

An 11.1V, 5000mAh Li-Poly 3S (three cells in series) battery pack of is employed to power the vehicle (see *Figure 7*).



Figure 7 – Battery used to Power the Quadcopter

It gives a flight time of approximately 15 to 20 minutes. To charge the battery, it must be unplugged from the vehicle and connected to an external battery charger. Suitable chargers are widely available.

4.3 Functioning

On start-up, the onboard computer initializes all the required software processes in much the same way as the ground robot (sensors, communication software, flight controllers, etc). Therefore, after the initialisation time (40 seconds approximately), you can access the control and monitoring website for operating the robot.

While the vehicle is on, the battery status can be observed in the control and monitoring website – a fully charged battery should show a voltage of approximately 12.4V. Moreover, the system has been programmed to perform an autonomous landing when the voltage drops below 10.5V.

5 Spider-like Robot

5.1 Powering

To turn on the robot, press the power button on the spider's belly. The led light should turn green.

5.2 Charging

The Hexa robot has a battery that allows around 45 minutes of continuous use. The robot includes a charging cable to connect the robot (connector on the bottom part) to a wall socket. The charging time is around two and a half hours.

5.3 Functioning

The robot has been configured to connect to the WiFi network of the robotic team on the start-up. It takes some time to setup everything after booting up the robot. The user can see the status of the robot according to the colour of the LED on the spider's head. When this led turns solid purple, the robot is successfully connected to network and ready to use. After that, the user just needs to access the control and monitoring website to operate the spider.

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6 Control and Monitoring Website

The control and monitoring website can be accessed by any computer connected to the network of the robot system. Note that, although the control software has been implemented as a website, it does not, of course, require a connection to the internet because the website is hosted locally. The IP of the computer in which the http server is located must be indicated along with the port 8080. In our case, the server is in one of the inner computers in the ground robot, so the address that the user must insert in his web browser must be: *http://192.168.0.3:8080*.

Figure 8 shows a capture of the control and monitoring website in a web browser. As general information, the website shows the status of the connection with the robots. And then, there are three general tabs that allow us to select between visualizing the data and commands of the ground robot, the aerial vehicle or the spider robot.

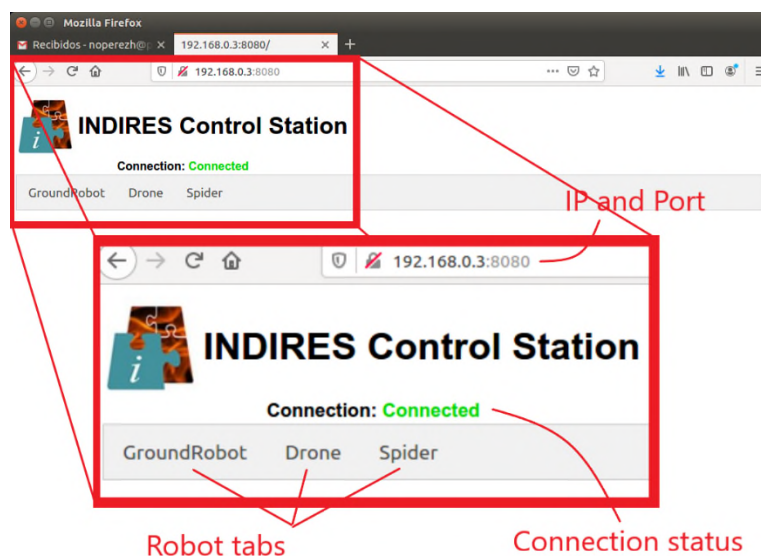


Figure 8 – Web Interface for Robot Control and Monitoring

6.1 Ground Robot Tab

An overview of the information and options that are available for the ground robot in the control and monitoring website are shown here.

The information is structured in different frames (see Figure 9):

- First, in the upper-left corner, is the video visualisation which allows you to watch the regular colour image or the image from the thermal camera.
- In the upper-right frame, we have a simulated videogame joystick seen from above. This joystick allows for teleoperation of the robot. While keeping the left mouse button pressed over the darkest inner circle, it can be moved in different directions over the lighter circle like a joystick. That triggers the teleoperation macro-action and cancels any other action in execution instantaneously. This way, you can take over the control of the robot at any moment.

- In the middle-right frame, there are two buttons that allow you to move the servo motors that grip the aerial vehicle and the spider to the vehicle processing hub. This way, the indicated robot is released or gripped to start or to finish its action respectively.
- Below the image visualisation frame, the Action buttons are located. You can launch the following four actions:
 - Start an autonomous exploration (the “Explore” button).
 - Navigate (autonomously) to a given local goal (the “Navigate Waypoint” button). In this case, the user must provide the coordinates, in meters, of the desired navigation goal regarding the current position of the robot. Moreover, this goal must be in an area not further than 5 meters from the robot according to the range of the depth perception of the camera in an unexplored space.
 - Navigate to the starting position (the “Navigate home” button). The robot will try to autonomously navigate to the position where the robot started to map the area.
 - Finally, you have the option of cancelling the current action (the “Cancel” button).
- In the bottom-right frame, you can see information about the general status of the ground robot. At the top, the level of the two batteries is shown (battery that supplies the motors, and battery that supplies the electronic components: computers, illumination, router, etc). At the bottom, the name of the action in execution and the status of that action is shown.
- Finally, the bottom frame is used to show the readings of the different environmental sensors mounted on the robot (though the final set is not completely configured in the capture shown).

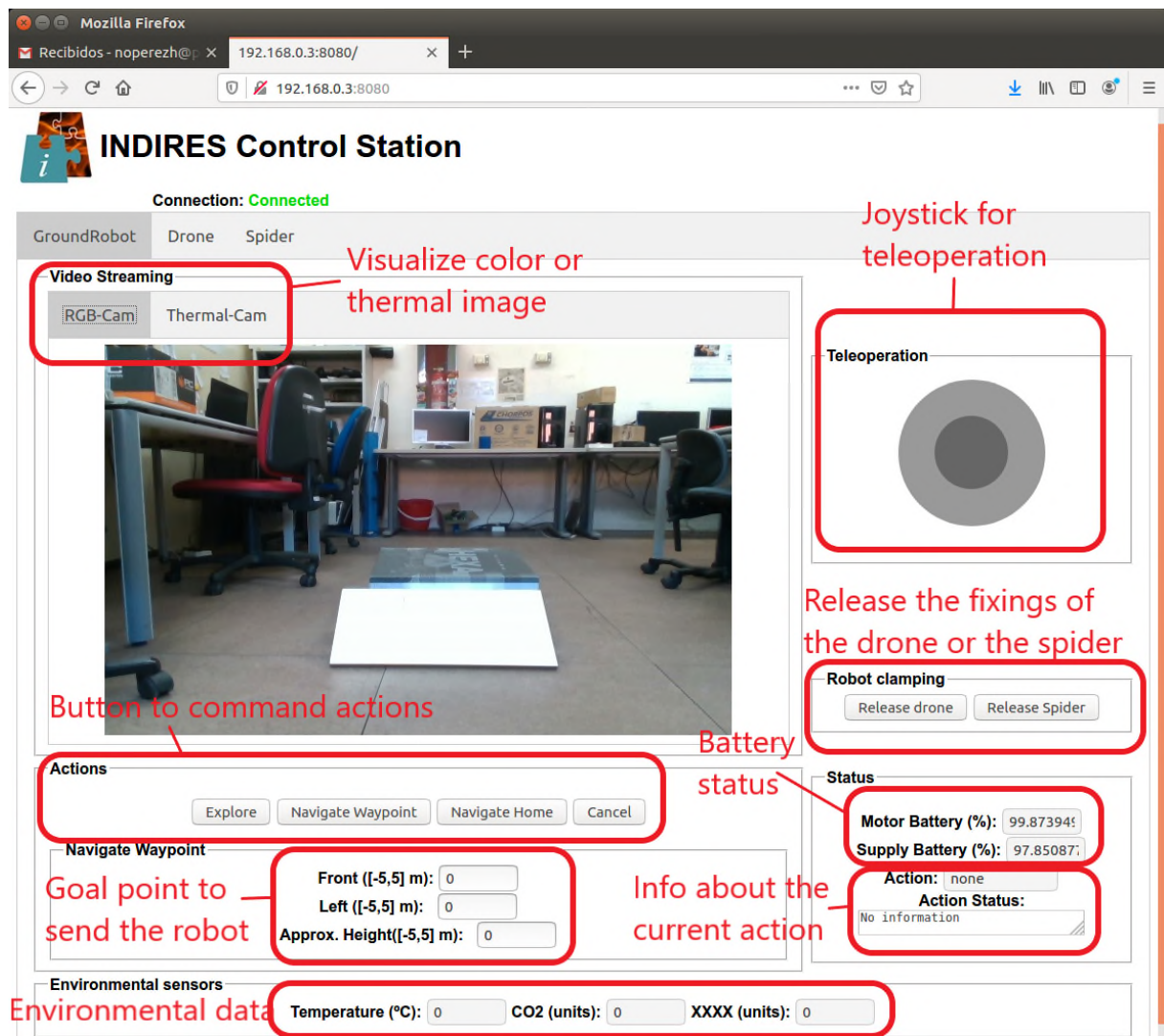


Figure 9 – Website Ground Robot Tab

6.2 Aerial Vehicle Tab

The drone tab is also structured in frames, like the ground vehicle. Some of the frames show information and others allow the user to command the aerial vehicle. The information and actions available are as follows (see *Figure 10*):

- At the top left we can watch the video streaming of the drone's front camera.
- In the top right frame, the following information is presented:
 - **Current voltage of the battery** This is important since the autonomy of the aerial vehicle is very limited (around 15 minutes).
 - **Armed status** This shows whether the drone is disarmed (the drone is on the ground and the propellers are stopped) or armed (already flying or ready to flight – rotors in movement).

- **The current mode of the drone** This should be “GUIDED” when the robot is navigating, “LAND” when the drone is landing, or “RTL” when the vehicle is coming back to its home position.
- A panel with extra information about the status of the current action.
- In the bottom right, the actions that can be commanded to the aerial vehicle are shown:
 - **Change altitude** First, you can select the desired altitude for the vehicle. This altitude is reached only if no obstacles are detected within a safety distance.
 - **Take off** If the drone is on the ground, the first action you can perform is to take off (the drone will reach the altitude indicated).
 - **Land** You can also send the order of landing. The drone will land on its current position.
 - **Return home** The robot will try to go back to its initial position where it took off. If obstacles are detected close to the drone, the drone will stop in the current position.
 - **Rotate** This action allows you to rotate the yaw angle of the drone. The angle and direction of rotation is given by the local navigation map in the bottom-left frame. You can drag and drop the blue circle and the drone will turn by the angle given by the front axis and the blue line that connects the center with the blue circle (see *Figure 10*).
 - **GoTo** This is the navigation action. It allows you to send a navigation goal to the drone within an area of 10 meters around it. The goal is given by the local navigation map. You must drag the blue circle to the desired position before pressing the “GoTo” button. The distance and direction are known thanks to the grid and axis represented. In this map the obstacles detected by the ring of ToF sensors are also shown in red (within an area of 7 meters around the drone). *Figure 11* shows an example in which an obstacle has been detected at the front-right side at a range of approximately two metres.

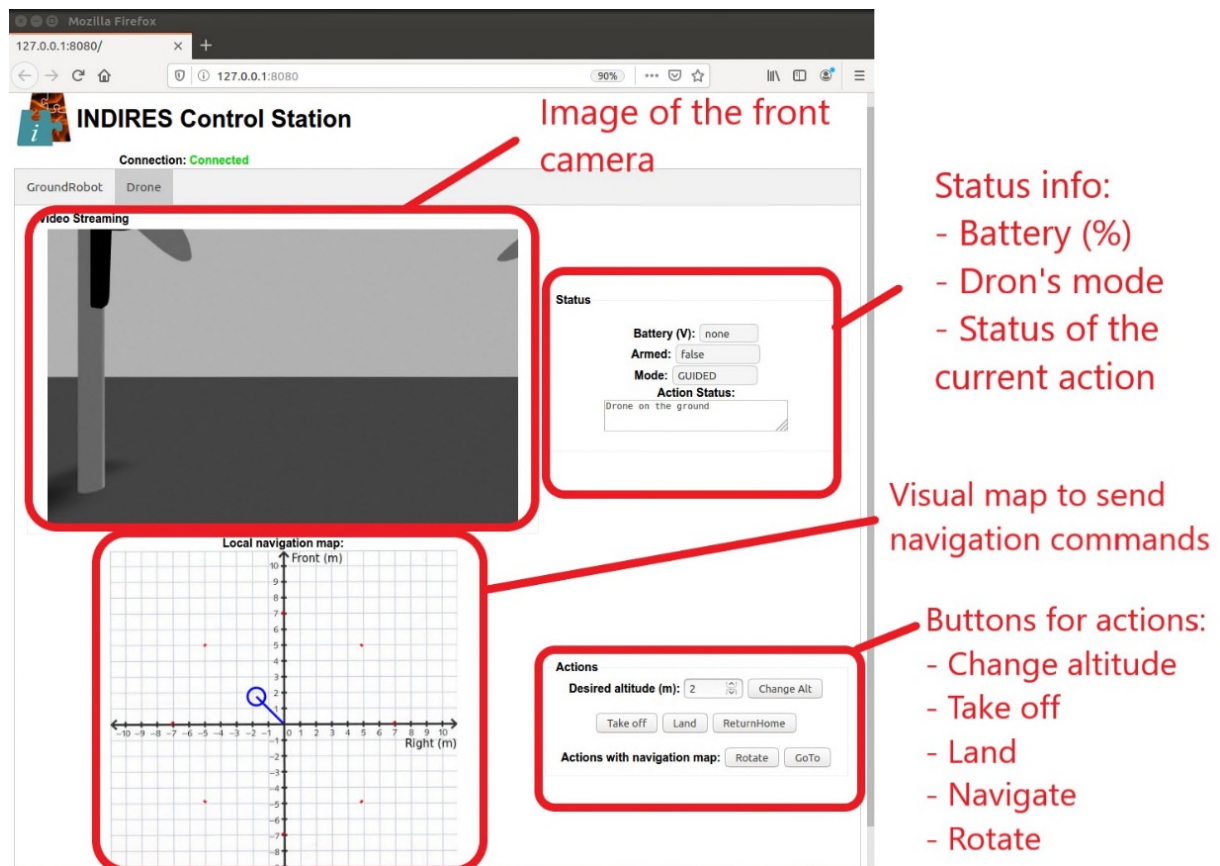


Figure 10 – Website Aerial Vehicle Tab

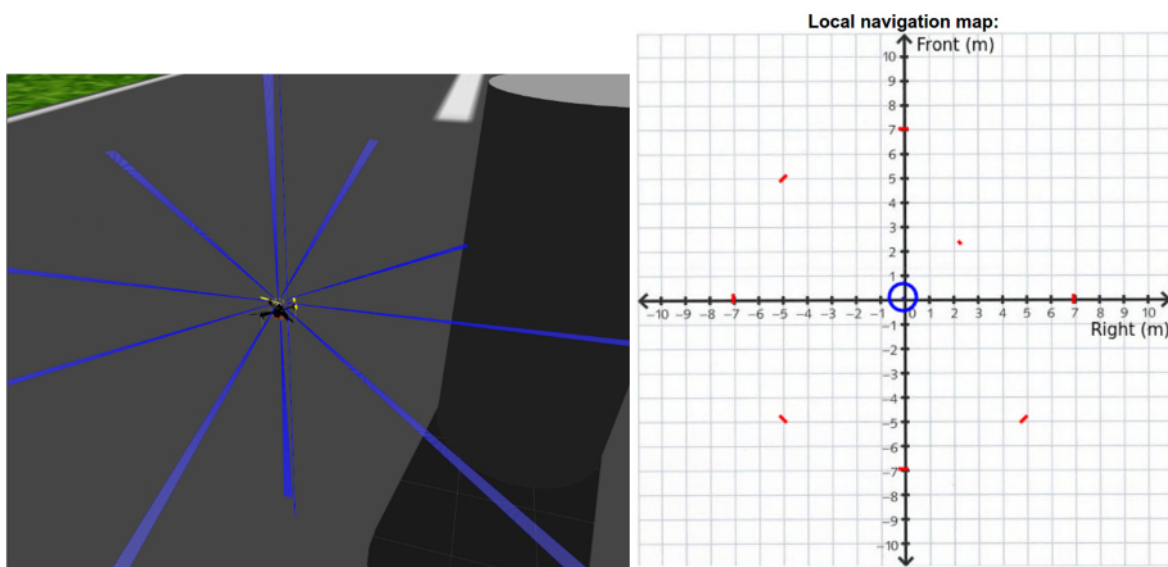


Figure 11 – Local Navigation Map for Commanding the Quadcopter

6.3 Spider Robot Tab

From the Spider tab, the video streaming of the onboard camera can be monitored. Moreover, there are different buttons to activate different pre-programmed modes that cause the spider move in different ways. Then, the movement of the spider (in the selected mode) is controlled through the arrow keys of the keyboard. *Figure 12* shows a capture of the information described.

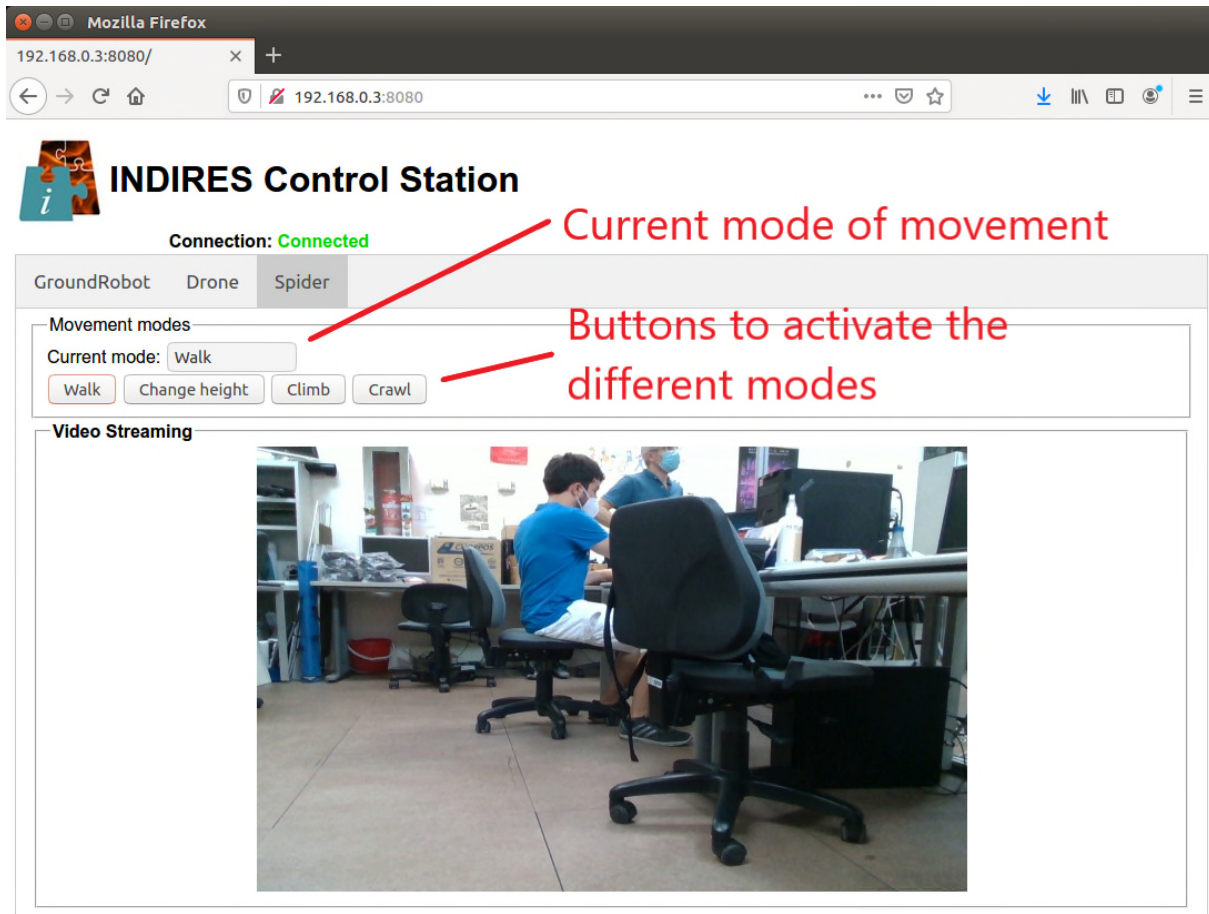


Figure 12 – Website Spider Robot Tab

The different modes available are:

- **Change height** This mode allows you to change the height of the spider core from the floor by changing the stretch of its legs. An example of the spider at its maximum height can be seen in *Figure 13*.



Figure 13 – Spider Robot at its Maximum Height

- **Walk** In this mode, the spider just walks at its maximum speed in the direction (and the height) that you have indicated. It is noteworthy that the forward direction is always the direction in which the spider's head is looking. The heading of the spider can be also controlled through the keyboard.
- **Climb** This mode uses the short-range distance sensor that is fitted to the spider, next to the camera. When an obstacle is close, the robot tries to overcome it. It is useful with small well-structured steps.
- **Crawl** In this mode, the position of the legs is changed. Three legs are moved to the front of the robot, and the other three to the rear, as can be seen in *Figure 14*. In this position, the spider can move forward slowly and crawl into small holes or cavities.



Figure 14 – Spider in Crawler Mode

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7 Further Information

Further information about the robotic vehicles deployment is available from the RoboticsLab Research Group at Universidad Carlos III de Madrid, Avda. de la Universidad 30, Leganes 28911, Madrid, Spain, <http://roboticslab.uc3m.es>.

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