The Lusi drone: a multidisciplinary tool to access extreme environments.

Di Stefano G. [1,*], Romeo G. [1], Mazzini A. [2], Iarocci A. S. Hadi 3, S. Pelphrey 4.
[1]Istituto Nazionale di Geofisica e Vulcanologia (INGV) – Rome – Italy
[2] Centre for Earth Evolution and Dynamics (CEED) - University of Oslo - Norway
3 BPLS, Surabaya, Indonesia; 4 Isotech Laboratories Inc, Illinois, USA

Abstract

Extreme and inaccessible environments are a new frontier that unmanned and remotely operated vehicles can today safely access and monitor. The Lusi mud eruption (NE Java Island, Indonesia) represents one of these harsh environments that are totally unreachable with traditional techniques. Here boiling mud is constantly spewed tens of meters in height and tall gas clouds surround the 100 meters wide active crater. The crater is surrounded by a ~600 meters diameter circular zone of hot mud that prevents any approach to investigate and sample the eruption site. In order to access this active crater we assembled and designed a multipurpose drone.

The Lusi drone is equipped with numerous airborne devices suitable for use on board of other multicopters. During the missions, three cameras can complete 1) video survey, 2) high resolution photogrammetry of desired and preselected polygons, and 3) thermal photogrammetry surveys with infra-red camera to locate hot fluids seepage areas or faulted zones. Crater sampling and monitoring operations can be pre-planned with a flight software, and the pilot is required only for take-off and landing. A winch allows the deployment of gas, mud and water samplers and contact thermometers to be operated with no risk for the aircraft. During the winch operations (that can be performed automatically), the aircraft hovers at a safety height until the tasks are completed while being controlled by the winch embedded processor. The drone is also equipped with a GPS-connected CO_2 and CH_4 sensors. Gridded surveys using these devices allowed obtaining 2D maps of the concentration and distribution of various gasses over the area covered by the flight path.

The device is solid, stable even with significant wind, affordable, and easy to transport. The Lusi drone successfully operated during several expeditions at the ongoing active Lusi eruption site and proved to be an excellent tool to study other harsh or unreachable sites, where operations with more conventional methods are too expensive, dangerous or simply impossible.

Keywords: Lusi mud eruption; Indonesia; drone; remote sampling; remote sensing

1. Introduction

Nowadays drones, or remotely controlled aerial vehicles, are ubiquitously present in a rich variety of human activities. Drones (or UAVs) provide the possibility to reach inaccessible localities offering the user the aerial view giving a new prospective compared with the traditional field observations. Aerial photography (from visible to multispectral) is undoubtedly the first discipline that enjoy greatly the advantage of this low cost, off-the-shelf and easy to use strategy to approach localities from the sky. Besides military approaches and applications, that tare largely top secret, drones are becoming more and more popular in the movie industry for spectacular panoramic images. Additional applications my include survey and search and rescue operations connected to emergency and disaster situations. The recent areal footages collected above totally destroyed and inaccessible towns in Italy after the 24th of August and 30th of October earthquakes (6.0 M and 6.5 M respectively), emphasized the advantages that the use of UAVs can provide. However, drones have the potential to complete many other operations if equipped with the proper instruments that are designed accordingly with the needs. One example is to go beyond exclusive visual data acquisition and physically access the ground completing in situ measurements or collecting samples and/or completing other remote-sensing applications.

This ambitious challenge was triggered by the need to study the Indonesian Lusi mud eruption. The 29th of May 2006 numerous aligned eruptions sites started in the NE of the Java Island in the Sidoarjo regency (Mazzini et al., 2007). These eruptions of boiling mud appeared following the same direction of the reactivated Watukosek strike slip fault system (Mazzini et al., 2009). Their erupting activity remained visible for several weeks until one of them submerged with mud a large area of 1.5 km^2. This major eruption site was named Lusi and it has been active ever since. Immediately started a massive effort to set infrastructures to protect the settlements; an intricate system of artificial levees and embankments was built including a circular berm framing the crater. This provided the unique opportunity to access the crater at a close distance. Until March 2009 the berm around the crater was maintained and when the operations stopped the gradual crater caldera collapse swallowed the only walkable way framing the eruption site. Within two weeks the two levees connecting the berm also disappeared and the crater remained since then totally inaccessible. A rectangular area of ~7km^2 is framed by a 15 m tall embankment. Lusi continues to erupt and the dry mud on the outskirts of the crater zone does not allow to approach closer than 300m. In order to endure the monitoring and the sampling initiated during the first years of the Lusi activity, it was concluded that the only safe way to access the crater was from the sky. In the framework of the ERC Lusi Lab project and in collaboration with INGV's NTS lab, we designed and constructed a multipurpose drone to survey the eruption site developing a set of drone born tools to allow geological measurement in the hostile Lusi environment. The design of the Lusi drone progressed accordingly with the goals of the project.

The purpose of this manuscript is to provide a technical description of the tools designed for the Lusi drone and their applications tested at the eruption site. A discussion of the various applications is given stressing their relevance for future works in different geological settings worldwide. We wish that this work will contribute to new ideas to complete missions at localities that are either impossible to access by man, or that would require too much time to be surveyed with traditional approaches. The results, interpretation and discussion of the data collected with Lusi drone will be completed in separate manuscripts.

2. General description, schematics and logistics

2.1 Drone configuration

The main requirements analysed for the construction of the Lusi drone were the budget affordability, the solidity, the integrity at high temperatures and humidity, the stability during strong wind, the easy transportation and assemblage, the electrical propellers, the versatility that is the possibility to add supplementary payloads for various instrumentations. The frame of the DJI s800 (DJI, Spreading Wings S800 User Manual) (Fig. 1.a) was selected as a skeleton to host the electronics, the selected flight controller and the various payloads to complete monitoring, sampling and remote sensing.

The drone offers a maximum take-off weight of 7.5 kg, and reasonable 15 minutes autonomy with 6 kg of take off weight (Gatti M. et al. 2015). With the Woo-Kong-M (WKM) autopilot (DJI, WooKong Multi-Rotor User Manual) it's able to hold the position in 18 knots wind which satisfies the field conditions at the Lusi site where the average wind is less than 10 knots. The drone electronics have been configured to host several payloads, using a simple interface that allows switching the payloads on the field. Several devices are permanently installed on the drone, while some of them can be removed to save weight in case of extended flights. The drone block schematic is depicted in Fig. 1.b.

The typical drone flight configuration is:

1. S800 frame
2. Wookong m autopilot (includes IMU, barometric altimeter, GPS and compass)
3. 900 MHz telemetry transceiver
4. 2.4 GHz Graupner GR24 radio receiver
5. Gimballed GOPRO Hero 3 for video log, aerial photography and FPV (First Person View)

6. OSD mixer and a 5.8 GHz video transmitter
7. Interface for payloads
8. Bluetooth interface for on field configuration

Items 5 and 6 can be removed to save weight and increase the flight time.
The GOPRO camera and the connected parts are installed in the front side of the vehicle, and their weight is compensated by the position of the batteries to keep the barycentre on the yaw axis. The camera orientation can be chosen by the pilot and the images, transmitted directly to ground.

The drone uses four different wireless channels to communicate with the ground.
1) A classical RC transmitter used to issue direct piloting commands
2) A bidirectional radio link that allows uploading the flight path for automatic operation, starting and terminating automatic flights and issuing piloting commands.
3) A BT interface that allows a wireless easy on-field set-up
4) A video transmission to see a real-time video from the camera and on-board instruments

Fig. 2.a shows the communication paths between the drone and the PC based ground station.
The drone can be manually controlled by a 2.4 GHz RC radio transmitter (generally used for take-off and landing) and automatically piloted by a ground station connected to the drone through a 900 (or 2400) MHz transceiver. The ground station allows a permanent connection to a rugged PC and it is used to define a mission, to upload flight plans, attitude data telemetry, to follow the flight on the map and to manage some automatic on board actions during the flight.
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The ground station accesses the Google maps satellite images and is equipped with a software (DJI PC ground station) that allows the operator to simply draw the flight plan on the pc screen. An example of ground station panel and flight path is depicted in Fig. 2.b. The flight plan is composed by a sequence of segments delimited by waypoints. A waypoint can be instructed to issue a command to the payload (i.e. to take a picture, operate the gas sampler, etc.). The ground station uploads the flight plan on the autopilot memory using the radio link, shows the drone position on the map and allows the operator to issue commands to the drone and to the payload during the mission. The ground station is set-up on the dry mud, 300 meters far from the crater.
A video receiver and FPV goggles allow the navigator to observe in real time the view from the drone during his flight path (Fig. 2.c), and to have a constant monitoring of the location of the drone during operations.
The payloads are located below the barycentre, and switching between payloads does not require tuning-up the vehicle ACS (Attitude Control System). The payloads are autonomous with a minimal mechanical interface based on simple sled fastening device and it is housed and tightened to the drone. The electrical interface between drone and the payloads consist of three electrical-protected connections: the power supply, when required, with an isolated dc-dc converter and the signal buffering lines for commands transfer. The payload can receive commands, directly and quickly by the radio or planned through the ground station; these commands are single Boolean values, operate or not operate, or PWM (Pulse Width Modulation) format commands used by RC model radio link.

2.2. Payloads, tools and their applications

2.2.1 The cameras

Aerial videos and images allow completing in a relatively short time mapping and data acquisition over large areas. Sky view provides the opportunity to observe features for global interpretations (up to centimetre scale) over spectacular geologic and natural settings and phenomena.

The Lusi drone can be equipped with three different cameras that can be used depending on the selected goal of the mission.

1-The gimballed GOPRO HERO3 remains installed during all the flights and can be used to complete either photogrammetry mosaic or videos. This tool represents a great benefit, for example for the selection of appropriate locations and opportunity to collect samples or deploy devices.

2-In the central part of the drone can be installed an Olympus EPM 2 a 16 Mpixel mirrorless camera that offers a in-body image stabilization and a simple electrical interface for focusing and shooting. This camera provides high resolution photos for the stitching of detailed mosaics. In our investigation area we completed photogrammetry with an overlap of 70 % of each image flying at a height of 50 m and at a speed of 4m/s. Repeated geo-referenced photogrammetry missions are useful to observe the evolution through time of e.g. active faults or to monitor the stability of a slope, analyse details of outcrops along cliffs, avalanches dynamics, glaciers advancement or retreat, dynamics of volcanic eruptions. A potentially great application for comparative photo mosaic surveys is the detection of potential inflation or deflation of the topography over selected areas. For example, data collection could provide evidence and warning at settings where gradual collapse is ongoing in case aquifers or shallow reservoirs are over exploited, where fluid migration is ongoing due to active tectonism or surface expulsion of fluids and rocks (i.e. classic eruptions), in case of subsurface karstic collapses, or dissociation of gas hydrates in permafrost regions potentially resulting in new born craters. In contrast topographic increase may occur in case if intrusive bodies or imminent volcanic eruptions, tectonically active compressional areas, excessive storage of in reservoirs or e.g. CO_2 sequestration. To sum it up, numerous are the potential applications for the use of comparative areal photomosaic for civil and geological purposes and to prevent or predict potentially hazardous situations. An ortophoto example of the Lusi surface is shown in Fig. 3, where over than 2000 photographs have been combined to produce a large detailed image. In the right side of the picture the photomosaic shows north side of the Lusi site and the effect of the pushing mud in the north direction, breaking the embankment (green area).

3-Ultimately a Flir I7 camera can be installed to collect thermal surveys of the targeted areas. This useful tool allowed us to define areas of particular interest such as e.g. the crater zone where fluids with different temperature are released with reoccurring patterns or defined zones inside the embankment where hotter fluids appear to the surface controlled by geological features.

2.2.2 Camera adapters

Two cameras housing (Fig. 4.a) have been designed and built to host the cameras used for photogrammetry and thermal photography (Olympus epm2 and Flir I7). They are two very light mechanical structures that fasten and hold the cameras in a nadiral position under the drone. Some dampers reduce away the vibrations of the propellers. These devices are generally used along with the electrical cameras interface already described. Since the Flir I7 does not provide an electrical input for shutting, the I7 adapter includes also a servomotor to push the shutter button.

An electrical camera interface (Fig. 4.b) has been designed to operate the Flir I7 and the Olympus EPM. This device is inserted to transform a signal from the radio, or from the autopilot, in a shot command for the cameras. When the operating signal is issued for a short time the devices triggers the connected camera once. This is useful for single shots taken automatically at waypoints or controlled by the drone operator. When the operating signal is continuously present, the trigger command is issued at regular intervals of time. The device is housed in a box clampable to the drone’s leg.

2.2.3 Gas samplers

Gas sampling is a technique that is typically used e.g. to monitor the air quality, in the hydrocarbon industry and at onshore and offshore venting or seepage sites in order to understand the reactions and the composition of the fluids and to define the depth of active systems. Gas sampling of inaccessible or dangerous sites represent one of the most challenging operations. In order to collect portions of gas erupted from the Lusi crater, the drone was piloted inside the tall plume released during the cyclical geysering events that characterize its activity (Karyono et al., 2016). The drone was s kept at a safe height in order to avoid any potential damage caused by the several metres sized mud bursts exploding in the crater. Gas sampling was completed with the use of Isotubes ®. Isotubes ® are metal sampling tubes, designed by Isotech laboratories INC, that allow instant sample collection and assure sample integrity and, if needed, long term storage. The tubes are pre-vacuumed before sampling, and it is sufficient to open one of the two valves located at the extremities to allow the gas surrounding the bottle to be vacuumed and be trapped inside. The flying gas sampler (Fig 5.a) may hosts up to 6 Isotubes® and allows a sequential operation of their valves. A built-in microprocessor opens the valve of the next empty Isotube®, and stops operating after opening the 6th tube. The sampling command can be issued manually o can be programmed in the flight plan as a waypoint operation, to be executed automatically. Six LEDs, each for every Isotube®, indicate which tube has been exposed. A second gas sampler, based on the use of pre-vacuumed inexpensive glass test tubes has been developed in the same framework. In this case the valve is replaced by a rubber cap that is pierced by a hypodermic needle to fill the tube (Fig. 5.b). Sampling gases from a multirotor can be done only if we assume a homogeneous gas concentration, and if the concentration cannot be modified by rotor's turbulence. Considering the velocity, the density and the dimensions of the Lusi crater plume (i.e. width of 50m) we consider the drone activity to be not perturbative. An additional arm may be attached to extend the gas vacuuming point outside the drone arms and thus exclude the perturbation effect. Using this clever technique, we managed to successfully collect gas samples from the erupting crater for further analyses.

2.2.4 Gas sensors

In order to map the composition and the distribution of the gas present at the eruption site we developed a kit of sensors able to analyse the gas composition during the flight of the drone. This is an autonomous sensor (Fig. 5.c), which includes a thermometer and a NDIR (Non-Dispersive Infrared) CO_2 and CH_4 sensors, equipped with a GPS and a data logger. When powered the devices continuously (one measurement per second) records gas concentrations, temperature, GPS position, and time and appends measurement in a file stored into an SD card. A built-in fan helps to convey the gas to the sensors. A LED indicates the proper functioning and the quality of the GPS signal.

2.2.5. Mud and water sampler

One of the priorities of the Lusi Lab project was to perform in situ measurements and collect fresh samples directly from the erupting crater (Fig. 6a). Given the vigorous activity, and thus the unfeasibility of crater landing, this goal was particularly challenging and could only be completed with the use of suspended tools.

The liquid phase released at eruption sites may provide valuable information regarding their origin (and thus the depth of e.g. the active conduit) as well as the reactions occurring during their rise to the surface. Water and oil are typically used for this kind of studies. In particular, oil can be used to understand the dynamics of the plumbing system through the history of the petroleum basin. Similarly, the mix of the solid fraction erupted in a clastic system as Lusi carries clues about the type of subsurface lithologies that are brecciated through the feeder channel. A detailed analysis and dating of the collected clasts or mud can be used to reconstruct a full stratigraphic succession or to define the source zone of the majority of the erupted mud. One example of such study can be seen in Akhmanov et al (2003). In their work the authors used erupted mud breccia clasts from a Mediterranean mud volcano crater to reconstruct the stratigraphic column pierced by the feeding conduit. Other interesting studies may be completed focussing on the microbial colonies thriving in the erupted sediments allowing us to explore the activity ongoing in the deep biosphere.

In order to collect samples of liquid and mud from the erupting crater, we developed a set of samplers. The choice of the sampler model depends on the targeted site and the type of liquid or mud present. The device is connected to the rope and deployed by the automatic winch. Each sampler model is constructed in Teflon®, stainless steel and aluminium, and can withstand temperatures higher than 100 °C. For low viscosity media (e.g. water-rich or oil fractions) it was designed a cylindrical sampler consisting of an vertically moving piston that allows the fluids to enter from the lower part of the sampler and that seals when tension is given and the piston is pulled upwards (Fig. 6.a).

For mud or clast-rich fluids, the high viscosity does not allow the sampler to sink and a mini grab was designed. This prototype is designed using principles similar to those applied for the Van Veen Grab Sampler typically used for seafloor sampling. The device is initially locked with a strong spring that is released when the lower part of the grab touches the ground and no more tension is present from the pulling rope (see details and functioning in Fig. 6.b).

The winch was designed to carry down the thermometer and the mud/water sampler in the crater zone. It is a microprocessor-controlled device that unrolls a line with a speed of more than 1m/s and detects when the suspended tool touches the ground. After sampling, the winch recovers the line. In case of emergency (i.e. the sampling or probing tool remains stuck in the mud) the winch can release the spool. This safety release operation will dismiss the attached tools but will allow a safe return of the drone to the base.

2.2.6 Geiger counter.

This device operates with a concept similar to the one used for the gas sensor. The counter (Fig. 7) measures with the interval of 1 second the number of discharges that occurred through a Geiger–Müller tube that is a fast, light and cheap way to approach nuclear measurements. The data, tagged with position and time from the built-in GPS are recorded on an SD card. This device can be particularly useful to map the presence of radioactive waste contamination areas as well as particular lithotypes present in the subsurface.

2.2.7 Thermometers

Spot temperature measurements are useful to understand the depth from which the fluids originate given a known geothermal gradient. Two types of thermometers have been used: a) a MadgeTech HiTemp140 and b) a MadgeTech PRTEMP1000a. The HiTemp140 is a stainless steel temperature data logger built for use in harsh environments. It is submersible, can withstand temperatures up to 140 °C (284 °F) and has an accuracy of +/-0.1 °C (0.18 °F). It can store up to 32,700 readings, and features a rigid external probe capable of measuring extended temperatures up to 260 °C (500 °F) when equipped with a Tephlon casing to protect the battery. The Fig 8.a shows the temperature measured during a mission to the centre of the crater, where the thermometer pulls down and touches the hot mud. PRTemp1000 is a rugged pressure recorder to accurately monitor and record pressure and temperature at user programmable reading intervals. The rugged stainless steel design allows the device to be placed in harsh environments. It can measure pressure ranges up to 5000 PSIA(G), and can withstand temperatures up to 125 °C (257 °F) and has an accuracy of +/-0.5 °C (0.9 °F). The described devices have booth an internal memory card and battery making them easy to deploy without additional external technology. Contact absolute measurements are extremely important since non-contact measurements (ir thermometers) are affected by e.g. the water vapour concentration and several other attenuation factors. Contact temperature measurements are also mandatory to establish ground truthing to validate remote sensing measurements over large and unreachable localities.

3. Work in progress

3.1 Parachutable buoy

In order to study the mud movement and the temperature behaviour at the crater zone, we designed a floating device that can either de deployed with the use of the winch, or directly dropped and parachuted from the drone. In the second case, the buoy is deployed by a releasing system, controlled by the ground station operator, or by the autopilot. After the release a parachute opens providing a soft landing of the device (Tiimus, K. et al. 2015). The device contains a GPS receiver, a radio transmitter and a digital thermometer. A microprocessor formats data and handles communications with the ground station sending GPS, time and temperature data to the receiving station. The buoy (Fig 8.a) is activated plugging the digital thermometer in the socket and allows few hours of data transmission. The autonomy of the device may vary depending on temperature, frequency of measurements and transmission of data. For temperatures up to 60°C the autonomy of the device can last up to some days. For higher temperatures, the batteries need to be cooled and this operation is completed by evaporating a coolant around the battery case. In this case, the autonomy depends on the maximum temperature and the nature and quantity of the coolant provided. This disposable buoy is still under development and has only been tested in the peripheral area of Lusi.

3.2 GPS-tagged contact thermometer

A cheap thermometer equipped with a GPS receiver has been designed to simplify the contact temperature measurements (Fig 8.b). This device records continuously temperature, time and position. Temperature spans from -55°C to 125°C, may be recorded with 0.05°C resolution. This instrument allows the performing measurements any time, regardless to the flight plan and without the need to identify the measurement points after the flight. The device is powered by plugging in the temperature sensor in the floating box; measurements are stored into an SD card. A LED indicates the proper functioning and the GPS signal.

4. Conclusions

This manuscript describes the details of the design and construction of the multi-purpose Lusi drone. This UAV is solid, light weighted, affordable, easy to transport, and successfully performed during several missions in extremely harsh environments such as the Lusi eruption site. The Lusi drone can complete standard tasks (i.e. aero photography) as well as numerous monitoring and sampling operations using in-house designed and built tools. Particular emphasis is given to describe the potential applications of the drone tools for extreme environments and/or specific circumstances and geological scenarios. Operations that are more traditional include video survey and photogrammetry of targeted areas. The drone is equipped with numerous extra tools that have been specifically developed and built to complete targeted operations at the Lusi eruption site, however these payloads can be used for the investigations at any frontier locality. These unconventional tools include infra-red camera, pressure and temperature loggers, gas sensors, gas samplers, liquid and solid samplers that can be deployed for spot measurements and sampling via an automated winch. The diffusion of off-the-shelf drones and parts makes the use of them cheap and easy, and the work described shows that, with a reasonable skill almost, any kind of equipment can be built and plugged to a drone.

The use of a drone also represents the only tool to safely reach inaccessible and dangerous areas such as cliffs, magmatic and clastic eruptions, areas where poisonous or corrosive fluids are vented. The price of a reusable drone is almost the same of on hour of a rented helicopter, and the advances in electronics allow drones with a good performance to fit in a backpack, and to become a companion of geologists in fieldwork.

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Figure captions

Fig. 1. Take-off of the drone and start of a mission on the Lusi crater. a) The DJI s800 frame; b) Drone block schematic. This is a typical drone assembly, built using off-the shelf parts. The payload interface block supplies power and signals to the exchangeable payloads. The GOPRO related parts (gimbal, OSD mixer and video transmitter) may be easily removed to lighten the drone.

Fig 2. Four different wireless channels to communicate with the ground: a) radio communication channels between the ground station and the drone; b) a ground station screenshot. The flight plan can be edited in advance, the PC keeps the map in memory allowing its use on the field even in case of Internet unavailability; c) the GOPRO camera installed in the front side of the vehicle and the pilot can choose the orientation. The images transmitted, directly to FPV, allow having a constant monitoring of the location of the drone.

Fig. 3. Photogrammetry example. On the right the ortophoto obtained by combining over 2000 photographs of the NE area of Lusi (green rectangle). Every spot in the lower left image indicates the position of the camera during the flight.

Fig. 4. Mechanical and electrical cameras-drone interface: a) Camera mechanical adapters that hold the cameras in nadiral position. Since the photogrammetry software compensates errors for camera orientation, a gimbal is not necessary for this task; b) The electrical INGV interface allows the cameras to be operated by the autopilot or by the RC radio. This device transforms a signal from the radio, or from the autopilot, in a shot command for the cameras (Olympus EPM2 and Flir I7 one at time).

Fig. 5. Gas measurements: a) the Isotube® based flying gas automatic sampler; b) gas sampler based on the use of pre-vacuumed glass tubes. In this case the valve is replaced by a rubber cap that is pierced by a hypodermic needle to fill the tube; c) gas sensor and data logger, housed in a box, ready to be attached to the drone payload's interface. In the middle the block schematic: sensor data are converted and acquired by the built-in microprocessor, tagged with GPS data and stored in a SD card. On the right, the methane concentration acquired over LUSI (2014).

Fig. 6. Water and mud sampling: a) left: A picture taken from the drone camera shows the sampling of the LUSI mud. Right: The Teflon liquid sampler connect to the automatic winch; b) the mud sampler and working principle: 1) the device is armed and ready for sampling; 2) when the device reaches the surface to be sampled, the ground surface pushes the feeler, and releases a clamp which releases the jaws; 3) the jaws are free to close, sampling the mud. The spring that drives the jaws (does not appear in the 3Dmodel) is visible in picture B), who shows the working prototype.

Fig 7. The drone born Geiger counter records discharge frequency and position during the flight. The device has been operating once over the LUSI craters without revealing any difference in the Geiger detectable radiation respect to the background.

Fig. 8. The crater temperature and the INGV contact temperatures sensors and data logger: a) Temperature profile during a mission of Lusi drone using a MadgeTech thermometer: take off, flying on the crater and contact with the hot mud; b) parachutable buoy. Released by the drone (right lower image) using an especially designed releasing system (upper right) this device (left) sends to the ground station temperature and GPS data; c) GPS-tagged thermometer. This device contains a data logger and a GPS and records continuously temperature position and time. Powered

by plugging the thermometer into the floating box it can be used to perform a series of measurements using the winch.

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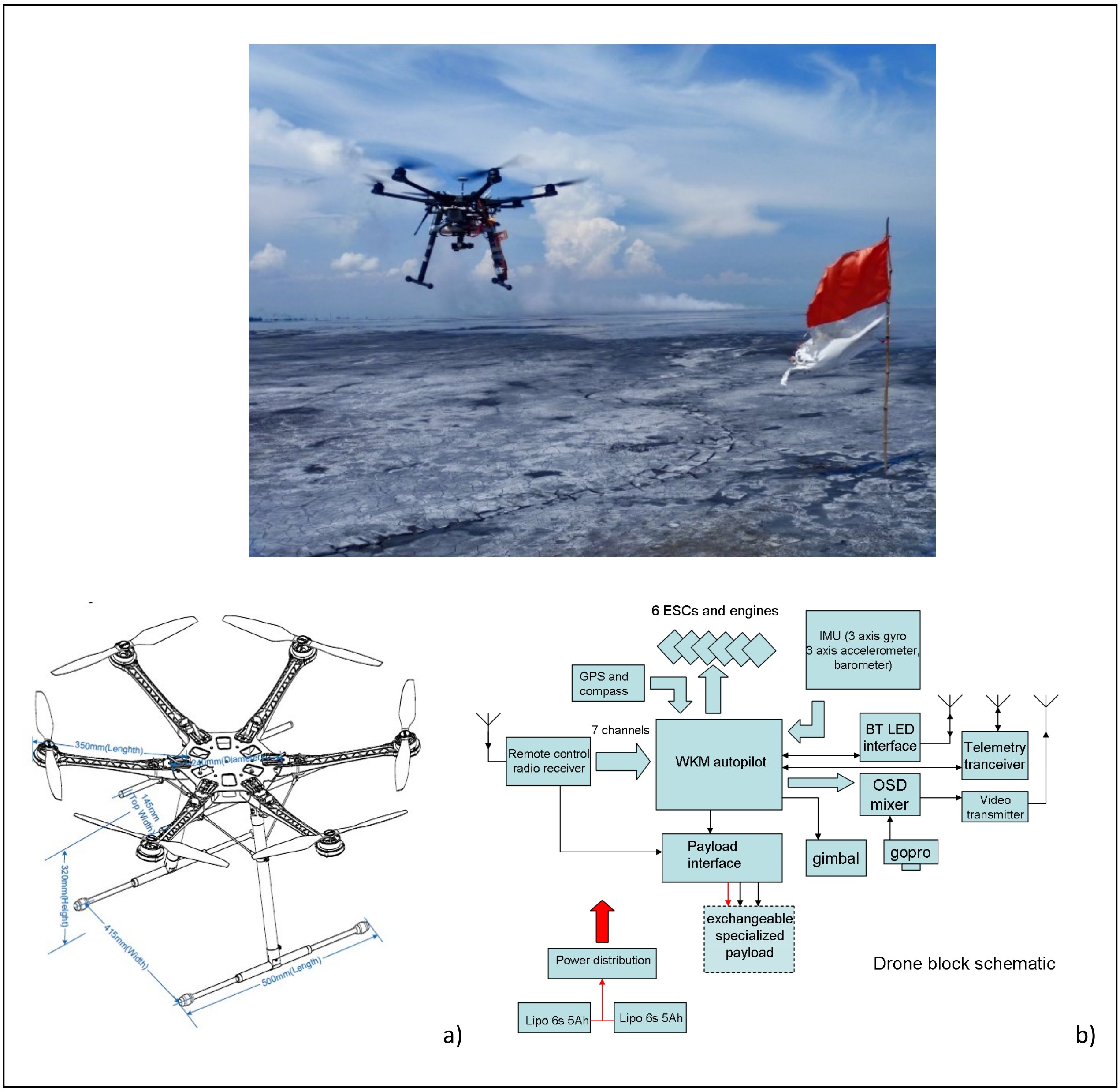
Figure n.1



350mm(Lenghth)
145mm
Top Width
320mm(Height)
415mm(Width)
500mm(Length)
a)
6 ESCs and engines
IMU (3 axis gyro
3 axis accelerometer,
barometer)
GPS and
compass
7 channels
Remote control
radio receiver
WKM autopilot
BT LED
interface
Telemetry
tranceiver
OSD
mixer
Video
transmitter
Payload
interface
gimbal
gopro
exchangeable
specialized
payload
Power distribution
Lipo 6s 5Ah
Lipo 6s 5Ah
Drone block schematic
b)

Figure n.2

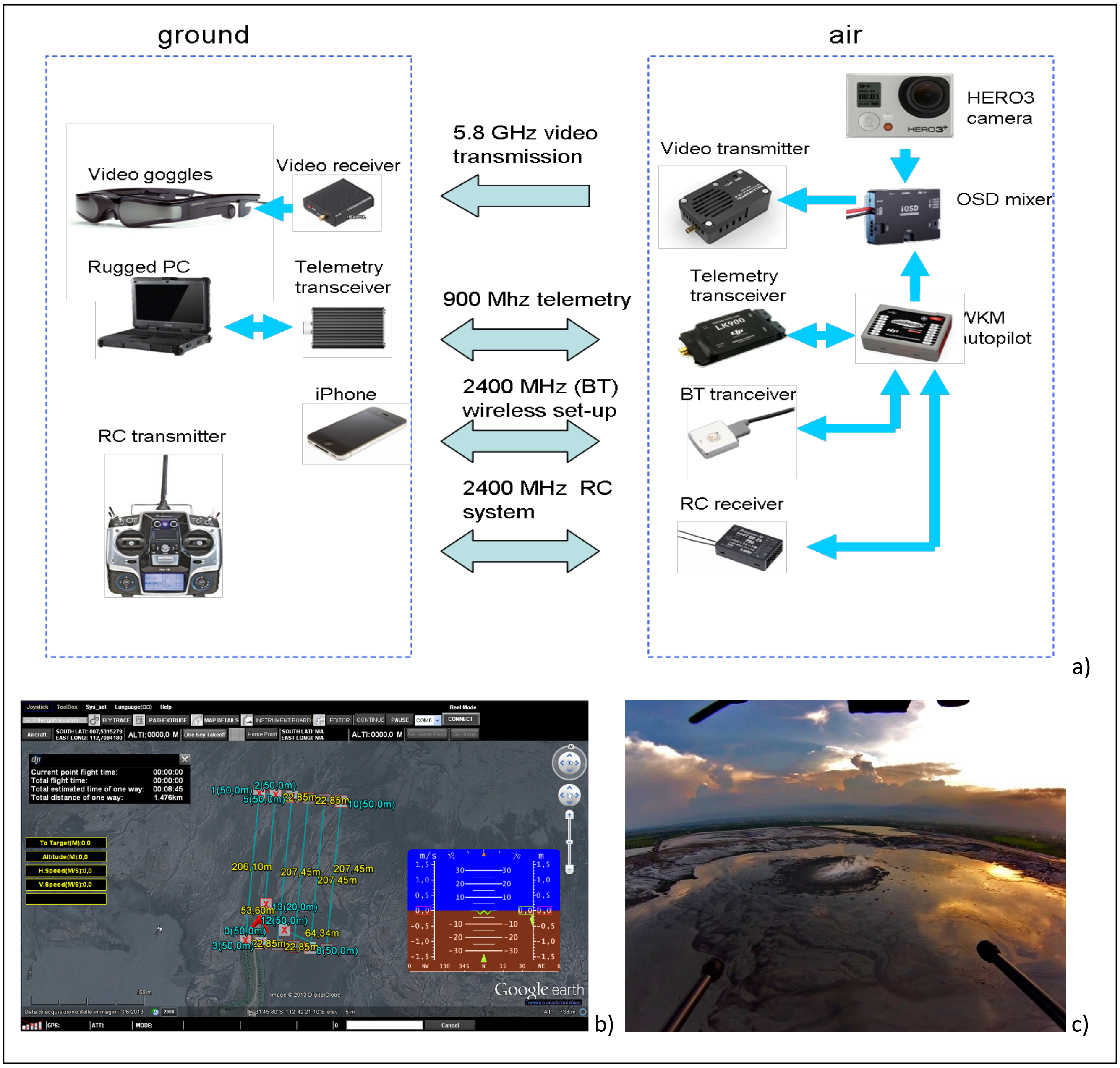

ground
air
Video goggles
Video receiver
Rugged PC
Telemetry transceiver
iPhone
RC transmitter
5.8 GHz video transmission
900 Mhz telemetry
2400 MHz (BT) wireless set-up
2400 MHz RC system
HERO3 camera
Video transmitter
OSD mixer
Telemetry transceiver
WKM autopilot
BT tranceiver
RC receiver
a)
Google earth
b)
c)

Figure n.3

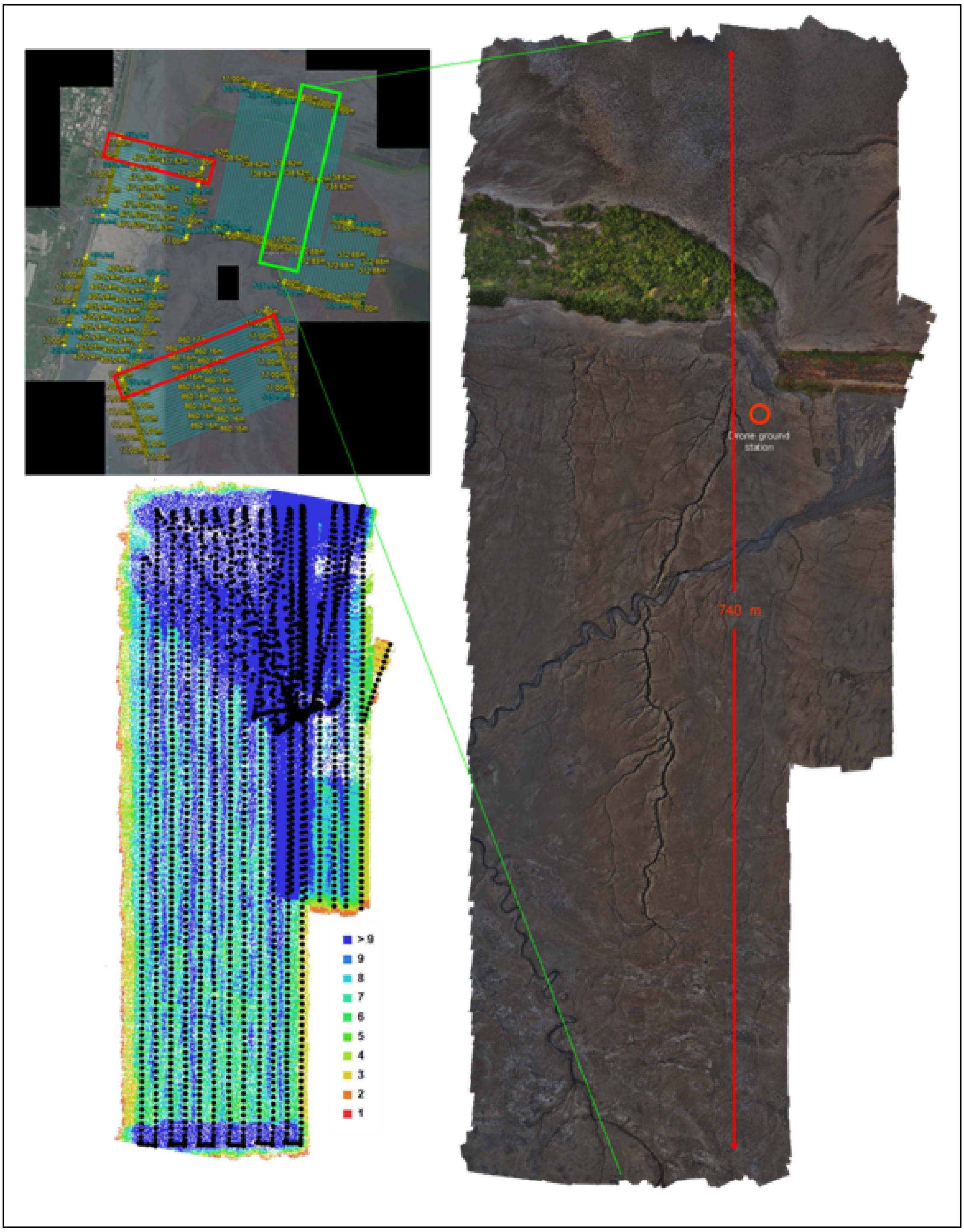


Figure n.4

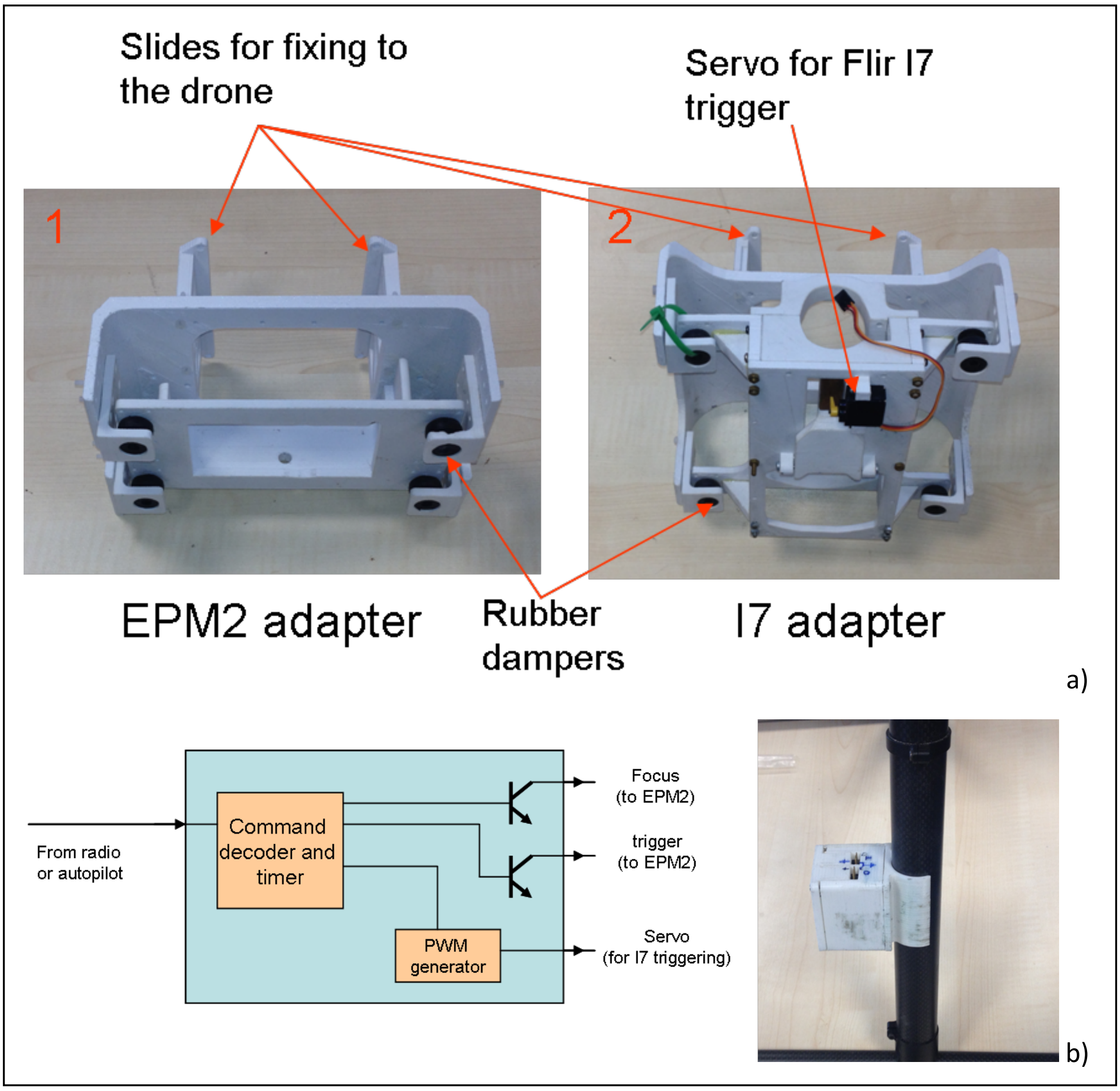
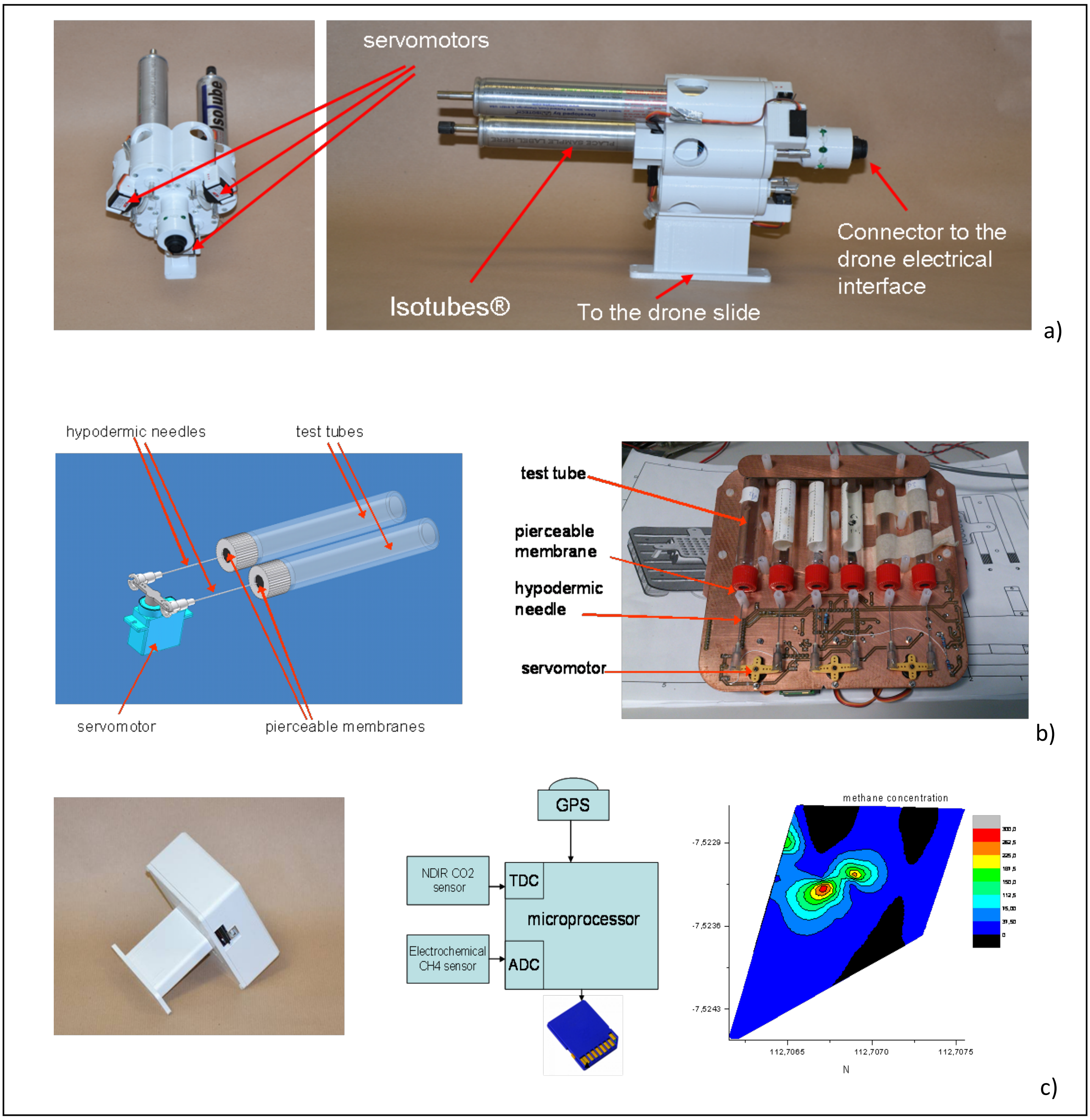

Slides for fixing to the drone
Servo for Flir I7 trigger
1
2
EPM2 adapter
Rubber dampers
I7 adapter
a)
From radio or autopilot
Command decoder and timer
PWM generator
Focus (to EPM2)
trigger (to EPM2)
Servo (for I7 triggering)
b)

Figure n.5



servomotors
Isotubes®
To the drone slide
Connector to the drone electrical interface
a)
hypodermic needles
test tubes
servomotor
pierceable membranes
test tube
pierceable membrane
hypodermic needle
servomotor
b)
GPS
NDIR CO2 sensor
Electrochemical CH4 sensor
TDC
ADC
microprocessor
methane concentration
-7,5229
-7,5236
-7,5243
112,7065
112,7070
112,7075
N
c)

Figure n.6

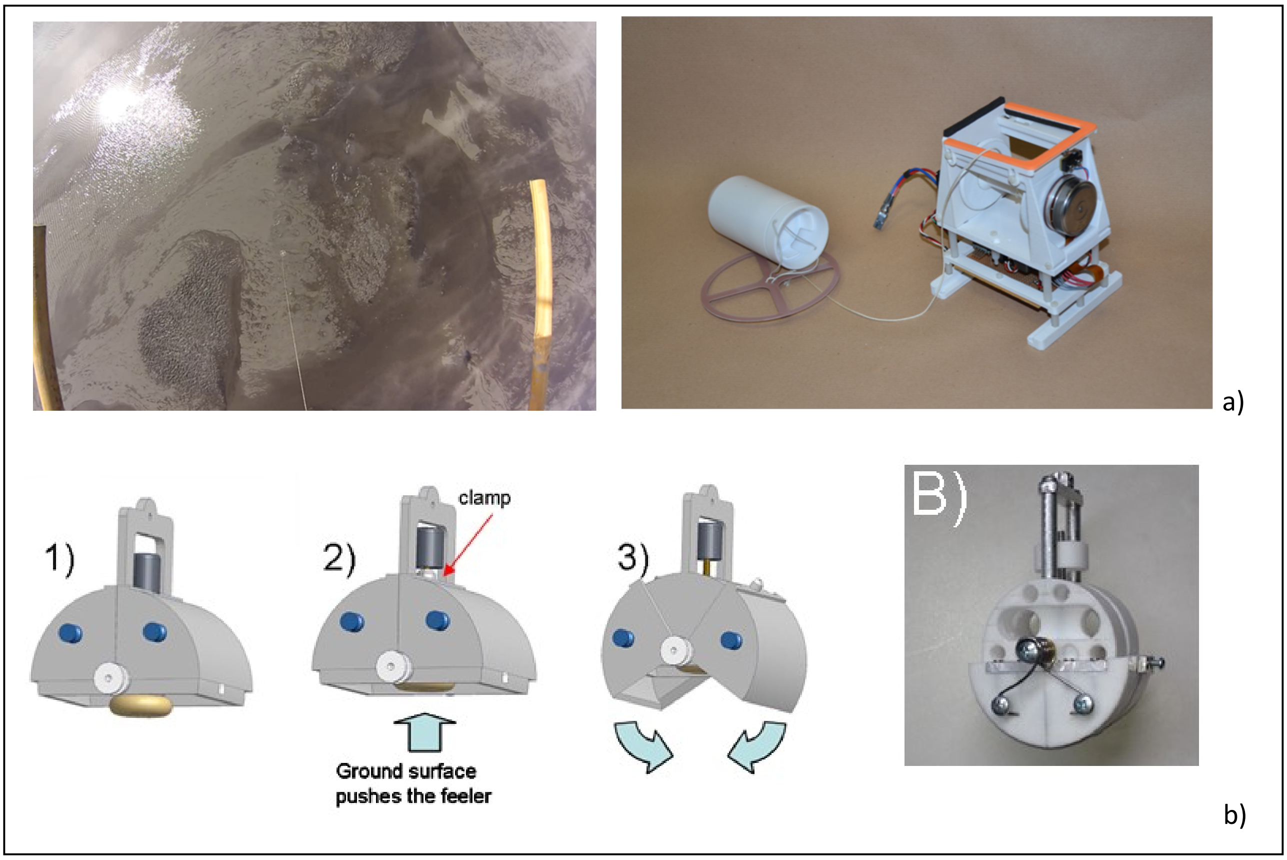


Figure n.7

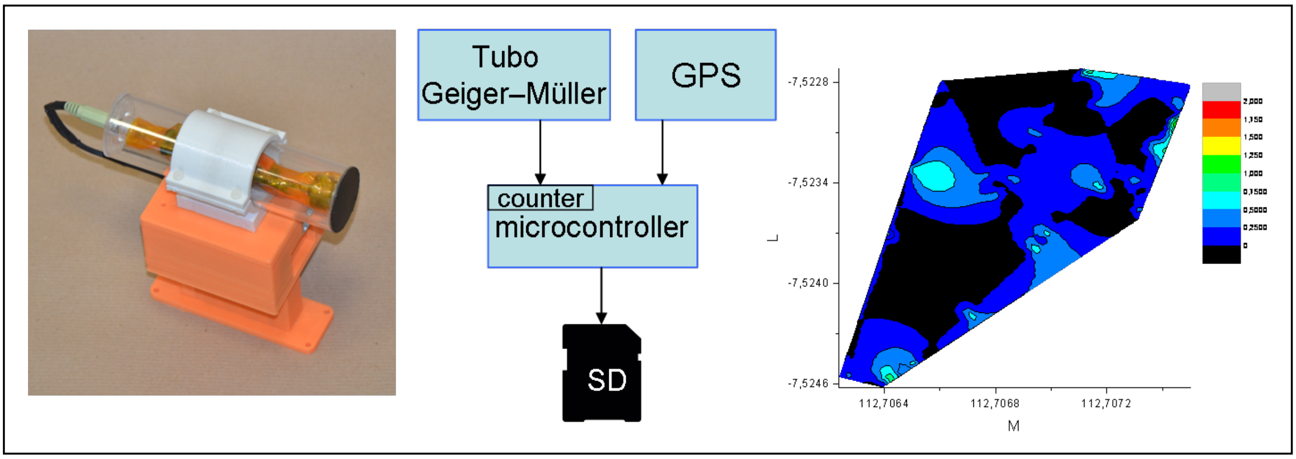
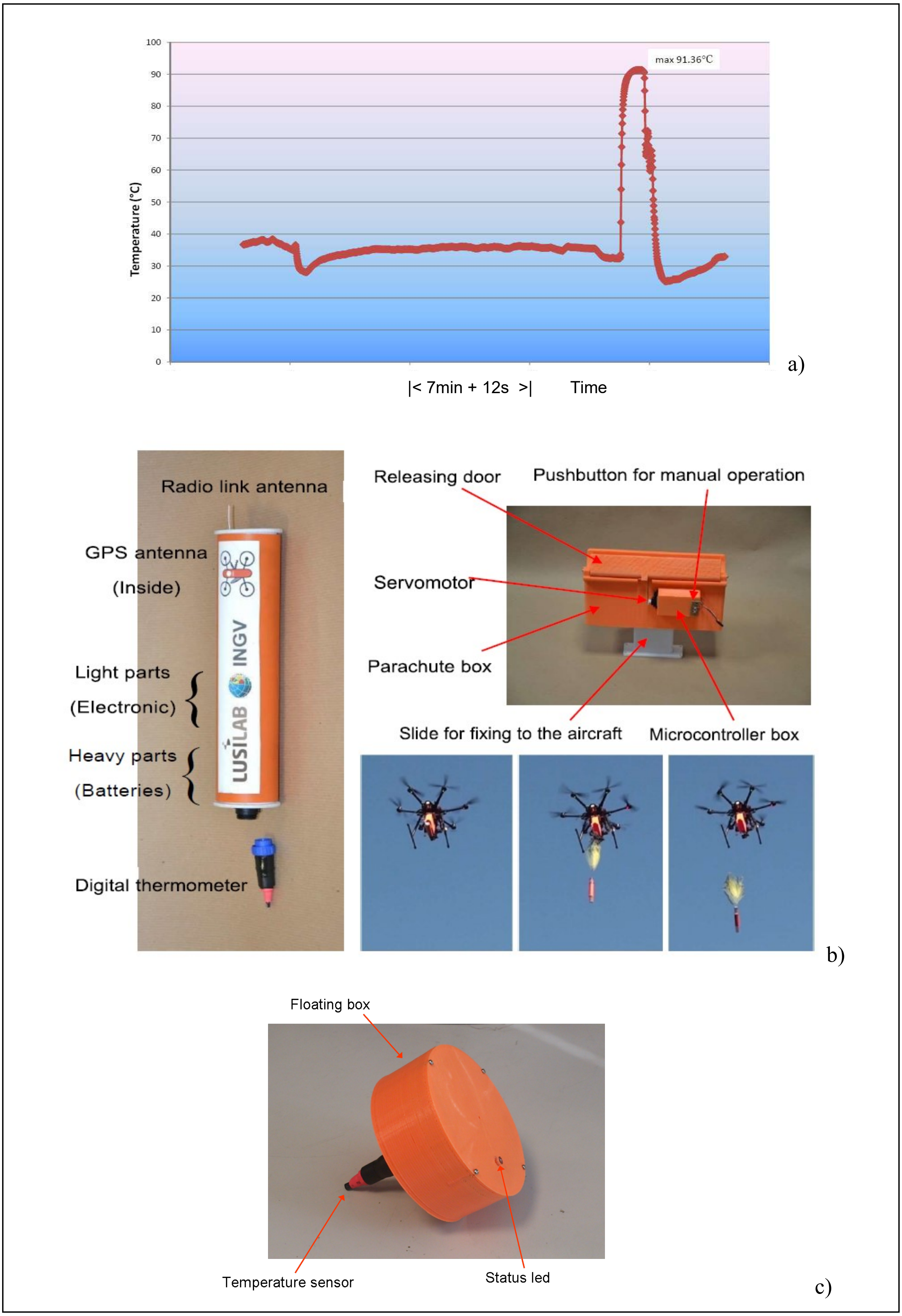

Tubo
Geiger–Müller
GPS
counter
microcontroller
SD
-7,5228
-7,5234
-7,5240
-7,5246
L
112,7064
112,7068
112,7072
M
2,000
1,750
1,500
1,250
1,000
0,7500
0,5000
0,2500
0

Figure n.8



100
90
80
70
60
50
40
30
20
10
0
Temperature (°C)
max 91.36°C
|< 7min + 12s >|
Time
a)
Radio link antenna
GPS antenna
(Inside)
Light parts
(Electronic)
Heavy parts
(Batteries)
Digital thermometer
LUSILAB
INGV
Releasing door
Pushbutton for manual operation
Servomotor
Parachute box
Slide for fixing to the aircraft
Microcontroller box
b)
Floating box
Temperature sensor
Status led
c)