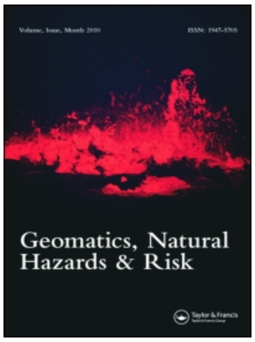
Multipurpose UAV for search and rescue operations in mountain avalanche events



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REVIEW ARTICLE

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Multipurpose UAV for search and rescue operations in mountain avalanche events

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ABSTRACT

This paper presents a multipurpose UAV (unmanned aerial vehicle) for mountain rescue operations. The multi-rotors based flying platform and its embedded avionics are designed to meet environmental requirements for mountainous terrain such as low temperatures, high altitude and strong winds, assuring the capability of carrying different payloads (separately or together) such as: avalanche beacon (ARTVA) with automatic signal recognition and path following algorithms for the rapid location of snow-covered body; camera (visible and thermal) for search and rescue of missing persons on snow and in woods during the day or night; payload deployment to drop emergency kits or specific explosive cartridge for controlled avalanche detachment. The resulting small (less than 5 kg) UAV is capable of full autonomous flight (including take-off and landing) of a pre-programmed, or easily configurable, custom mission. Furthermore, the autopilot manages the sensors measurements (i.e. beacons or cameras) to update the flying mission automatically in flight. Specific functionalities such as terrain following were developed and implemented. Ground station programming of the UAV is not needed, except compulsory monitoring, as the rescue mission can be accomplished in a full automatic mode.

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KEYWORDS
Avalanche; UAV; search and rescue; beacon

1. Introduction

During last decade the number of people practicing winter sports activities in mountain environments has increased as evidenced in several scientific publications by alpine clubs, research centres (Valt et al. 2009; Techel et al. 2015) and also in market surveys (SIA 2015).

One of the greatest hazards for recreationists and professionals is avalanches that in Europe alone cause tens of deaths each year. Most of them are asphyxia-related which is confirmed by the hard drop of survival probability after 10 min after being buried (Haegeli et al. 2011). So it is essential to minimize the time of time a person is buried. The user interface available in the modern avalanche beacons (ARTVA) guides the rescuer during the search phase reducing the search time. This is helpful for auto-rescue situations when stress strongly influences the operations. The effectiveness of these devices is confirmed by a stable number of deaths regardless the increase of sportsman and recreationists (Techel & Zweifel 2013). Other technical solutions are designed to limit the effect of burying by using airbags (Haegeli et al. 2014) however their drawbacks are sizes, weight and cost.

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Even if modern avalanche beacons are valid and reliable, the operational range (currently about 60 m (Meister & Dammert 2014)) influences the rescue time. In real operating conditions, this range is reduced by several factors like ambient noise, interference with other electronic devices or other beacons. In common practice the scanning is performed using 10–20 m search strip widths. Furthermore, rescues usually get more complicated by the environment and morphologic conditions of avalanches.

The recursive methodology of this kind of search offers the opportunity to use automatic devices like drones (UAV). These systems perform the required tasks autonomously, accurately and without exposing the rescuers to additional risks due to secondary avalanches.

Unmanned aerial vehicle and systems (UAS) are nowadays becoming more and more popular in several applications. Even though a complete regulatory framework is not available yet in many countries, research prototypes and commercial applications are spreading. The development of highly integrated electronics and subsystems specifically meant for the application, better batteries, miniaturized payload and, in general, affordable prices, has made available small UAVs with very good performances. These technologies can bring benefits also to the mountain operations especially in emergencies and harsh environmental conditions, such as search and rescue (SAR) and avalanche rescue missions.

As demonstrated by volunteer organizations like SAR Drones (SAR Drones 2016), the applications in mountain environment are today very few and do not seem to go beyond the preliminary prototype level.

The Alcedo project (ALCEDO 2009), started in 2009 to develop and build a prototype based on a lightweight and foldable quadrotor with a set of highly sophisticated localization and navigation algorithms, based on GPS, to localize a detected victim within less than 10 s (Grauwiler & Oth 2010). The approach is very similar to the presented work, but few experimental results are presented.

Similarly, Delta Drone, a French company working on UAV services, filed a patent (Serre et al. 2012). Besides some technical solutions, it claims about ‘a trajectory planning unit modifies the plan based on the intensity of the signal emitted by the target and measured by the measurement unit, where modification of the flight plan corresponds to a spiral trajectory when the target is detected. An independent claim is also included for a method for searching avalanche victims utilizing a flying object.’ Also in this case no practical implementations are available in the scientific literature documenting the feasibility and achieved performance.

An intensive investigation (Joern 2015) describes the usage of UAVs, with thermal imaging, to identify victims of avalanches; it is based on methods of geographic information system (GIS), remote sensing and aims to provide a solution for a quick and reliable search and rescue mission. Results were mainly focused on image analysis rather than the whole system integration. Similarly, AerialTronics (2015) customized one of their systems to provide a cheaper, safer way to incorporate aerial assistance in SAR operations. Their systems can be readily available due to their modest size, provide normal as well as thermal images that can be available in real time.

McCormack and Stimberis (2010; McCormack 2008) present the experimental evaluation of fixed and rotary wing UAVs for conducting snowpack, terrain surveillance and for accurately dropping explosive charges such as those used to trigger controlled avalanches. They also talk about regulatory issues.

Many other projects can be found on the web, like the airborne avalanche rescue system, that shows the results of a designer, Tatjana Rolle (2011), aimed to decrease crucial emergency rescue times after avalanches by utilizing autonomous airborne drones to detect and mark the position of victims.

Since 2013 the SHERPA project, funded by the European Community’s 7th Framework Program (Marconi et al. 2013), works on addressing the development of a team of ground and aerial robots to act as an aid to alpine search and rescue missions. Currently, some results of using a quad-rotor UAV equipped with avalanche beacon have been shown. The main project goals are collaborative operation as summarized by SHERPA 2013.

Despite the idea, general feasibility and algorithmic part are presented in many cases, a complete system development, from concept to the test of a real demonstrator and quantitatively showing its performance has not been presented yet in the scientific literature.

Starting from the experience made by the authors in UAV fields and in mechatronics devices for mountain safety (Tonoli et al. 2014) and (Tonoli et al. 2016), the aim of this work is to study, develop and test a system for avalanche rescue mainly based on the beacon technology. The proposed solution is designed to be completely autonomous, adapt to the harsh weather condition, and to be easy to transport, deploy and use. The system is based on a commercial UAV that has been modified by installing an avalanche beacon receiver and its processing unit, a laser sensor for terrain following, and automatic inflight reprogramming; finally, it has been experimentally tested to prove the functionality in real environment and to document the achieved performance in terms of search accuracy and time.

2. Problem description

Avalanche survival time is the most important aspect to be considered. An updated study of avalanche survivability statistics (Haegeli et al. 2011) indicates that survivability chances are significantly lower than previously thought. As shown in Figure 1, according to this study the survivability drops below 80% after only 10 min of being buried.

The prompt rescue with the help of technical devices such as avalanche beacons, probes and snow shovels, as well as the thorough knowledge of the 'search and extraction' procedures by all teammates constitutes the best chance of survival for snow-covered people. Nevertheless, in many cases the intervention of external rescue teams is the only possibility. In these cases, the logistic problems due to the harsh environment increase the rescue time with associated higher risk of death.

3. Proposed solution

In the present work, an UAV equipped with visual/thermal cameras and avalanche beacon has been evaluated as a means to better support the rescue operation.

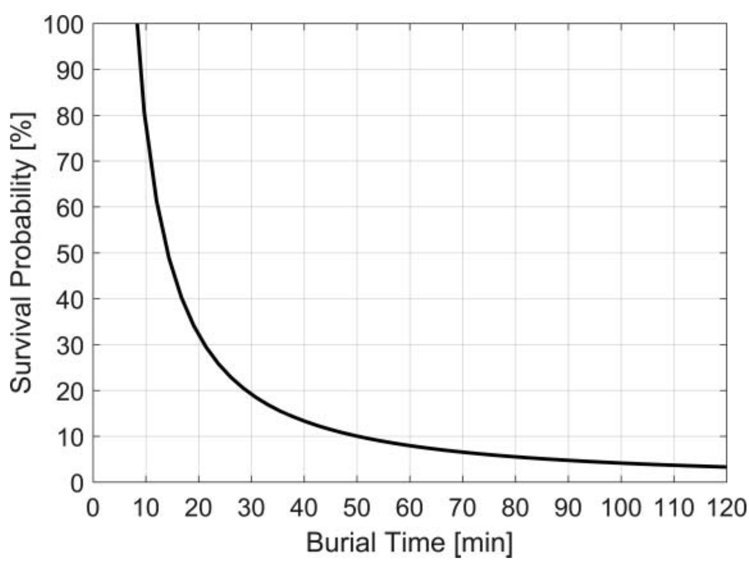

Figure 1. Survival curve for people completely buried in avalanche as function of the duration of burial.

A preliminary investigation was performed using classical SAR based on real time visual and thermal imaging of the investigated area. Even if results are coherent with the expectations, some relevant limitations became evident:

- This kind of mission requires highly skilled personnel to evaluate the video coming from the field. Additionally, the mission requires typically more than one operator to fulfil flying and observation tasks.
- With the currently available thermal imaging technologies (in this case a FLIR Tau 2 IR camera) a layer of snow covering the buried person of no more than 10–20 cm is enough to prevent the identification of any thermal sources, as shown in Figure 2, where the buried person is partially covered by snow except part of his head, arm and knee.

The option package delivery was investigated in terms of payload capability but is not reported in this manuscript because it was considered less relevant to the search operations, which is the main topic of this work. Similarly, the visual/thermal search was not investigated in more detail because of the intrinsic limits of these sensors in cases of total burial. According to these considerations the activity was focused on the beacon as search sensor, its integration with the UAV system and the autonomous flight planning with the aim of understanding its potential in reducing the time needed to find a snow-covered body (SCB).

Some aspects, that deal with the infrastructure than to the flying system itself, were not investigated. The UAVs transportation to the avalanche area, the collaboration with the rescue teams and a possible system architecture, capable of managing the operation from the warning to the mission completion, are under study and they are not reported here.

Also, some technical aspects related to UAV technologies such as batteries performance at low temperature, redundancies of the UAV, are not reported for brevity.

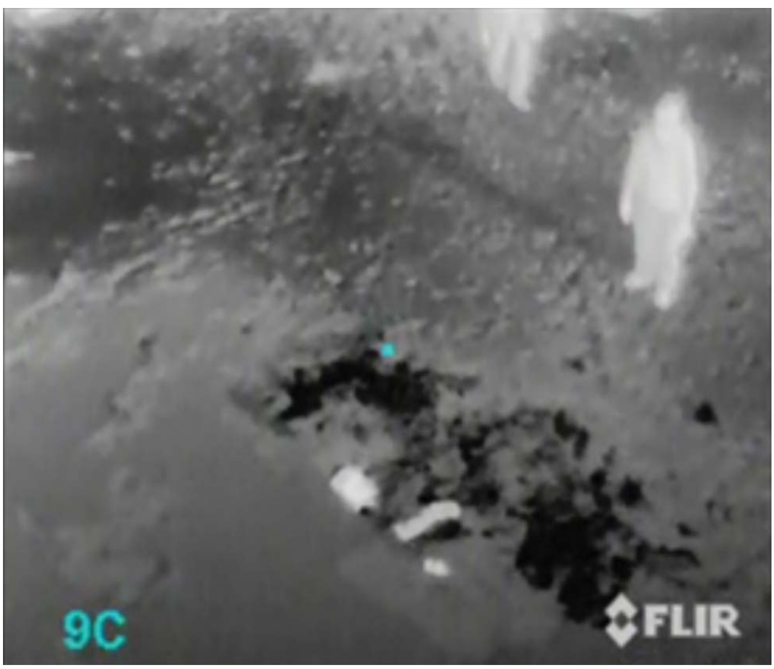

Figure 2. Aerial images shot with a FLIR Tau 2 IR camera on the emergency site: in the bottom the partially buried with only the uncovered head, arm and knee visible.

3.1. UAV required specifications

The set of requirements for selecting the commercially available UAV were established according to the search task:

- Full autonomous flight: including take-off, waypoint navigation and landing.
- Capability of flying without a ground station in full autonomous mode with failure management capability (battery, link, etc.)
- Payload capability: about 1–1.5 kg, to carry avalanche beacon and thermal camera.
- Easy transportability and operability: also in mountain environment.
- Good flight performance: stability also in windy conditions and robustness to set-up (load) changes.
- Endurance: at least 10–15 min at full load.
- Possibility of system integration: interaction with different payloads.
- Easy customizability for mission planning/re-planning, fly management and system integration.

The selected UAV is Venture UAV produced by PROS3 (PROS3-Venture 2015) customized for the specific application in order to accommodate the developed payload. Figure 3 reports the main dimensions of the UAV, while Table 1 summarizes its main characteristics.

The UAV is equipped with a MicroPilot 2128g2Heli (MicroPilot 2015) autopilot that offers the possibility of integrating custom payloads, and to define custom flight operations. It is based on a temperature compensated (−40 to 85 °C) inertial measurement unit (IMU), so temperature drift and biasing is automatically zeroed during operation. This capability allows very fast on site deployment, as no calibration procedure is needed. Furthermore, the autopilot offers a set of automated warning/failure procedure that can be activated autonomously (i.e. specific flight program in case of

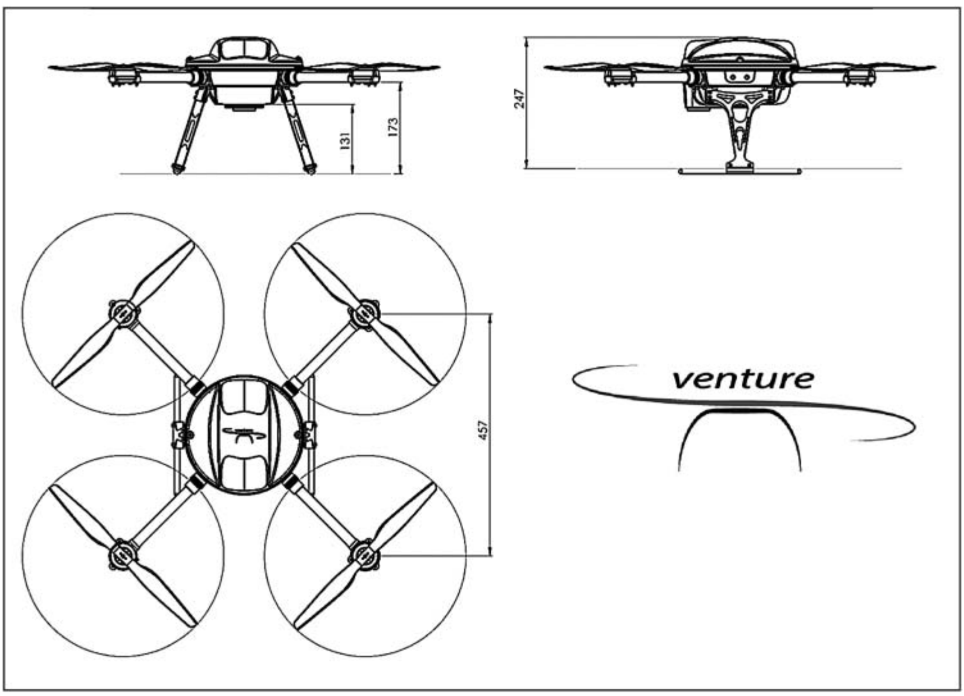

Figure 3. Venture UAV by PROS3 – main dimensions (courtesy of PROS3,www.pros3.eu).

Table 1. Venture UAV by PROS3 – main characteristics.

Description	Unit	Values
Overall dimensions (ready to fly)	mm	838 × 838 × 247
Overall dimensions (folded)	mm	549 × 266 × 266
Max. T.O. weight	kg	3.0–3.5
Cruise speed (typ.)	kph	30
Wind speed (max)	kph	15
Flight endurance (no payload)	Min	30
Standard datalink range	km	2
Empty UAV weight	kg	2.1
Battery weight	kg	0.6
Battery type	LiPo – 6s1p 4600 mAh	

battery warning/loss of remote control (RC) link/loss of ground control system (GCS) link, if present/sensor calibration error/bad GPS speed accuracy). Further detail about autopilot and embedded sensor performances can be found in manufacturer's documentation (MicroPilot 2014). The autopilot fuses data of IMU and GPS for navigation, so GPS fix is currently mandatory for autonomous flight. In this research the authors assumed the availability of a consistent GPS position that sometimes, especially in mountains, is not possible. Several papers (Luo et al. 2013; Masiero et al. 2015) are present in the literature about navigation with poor or without GPS signal, showing techniques that can be adopted to increase the proposed system reliability and operability.

3.2. Avalanche beacon integration

Typical avalanche beacon systems (ARTVA) include a transmitter and a receiver that can be activated during the search for the SCB. The signal includes a 2 kHz burst of about 0.1 s each second on a carrier frequency of 457 kHz (ETSI 2001). An analog receiver (Barryvox VS 2000 PRO EXT) (Girsberger 2005) with a special high gain ferrite antenna (terrestrial long range) was selected for the project. Modern digital avalanche beacons are equipped with multiple antennas, microprocessor, embedded software and a user interface that guides the rescuer to the target. Nevertheless, the analog receiver was preferred because of its better sensitivity, the possibility to fully manage the signal without signal processing delays and the difficulty in getting access to the processing algorithms embedded in digital systems. The selected beacon has an audio-like output that needs to be processed to extract the information about the presence of the transmitter in the antenna range. Two approaches were followed to this end.

In the first one, the receiver sends the signal to ground from the UAV using a video/audio analog transmitter and it is processed there. This reduced the weight carried by the UAV but is prone to signal degradation and requires a ground station.

In the second instance, an embedded system (based on digital signal processor (DSP)) processes the signal on board the UAV. This avoids signal degradation due to transmission to ground and allows the UAV system to be fully autonomous with a smaller, more compact and integrated solution that avoids ground devices.

3.2.1. Retractable antenna system and UAV integration

The relatively low working frequency of the avalanche beacon makes it very sensitive to electromagnetic noise, especially if the antenna and receiver are close to the UAV's avionics which include microcontrollers, power electronics, batteries and electric motors. A suitable position for the receiver antenna was determined to be the lower part of the UAV at a distance of about half a meter. This distance was found as a compromise between the need of reducing the electromagnetic noise captured by the antenna on one side and that of preserving the manoeuvrability of the UAV on the other. A large antenna-UAV distance will increase the weight, and considerably affect UAV manoeuvrability. In the adopted configuration, the background noise coming from UAV subsystems

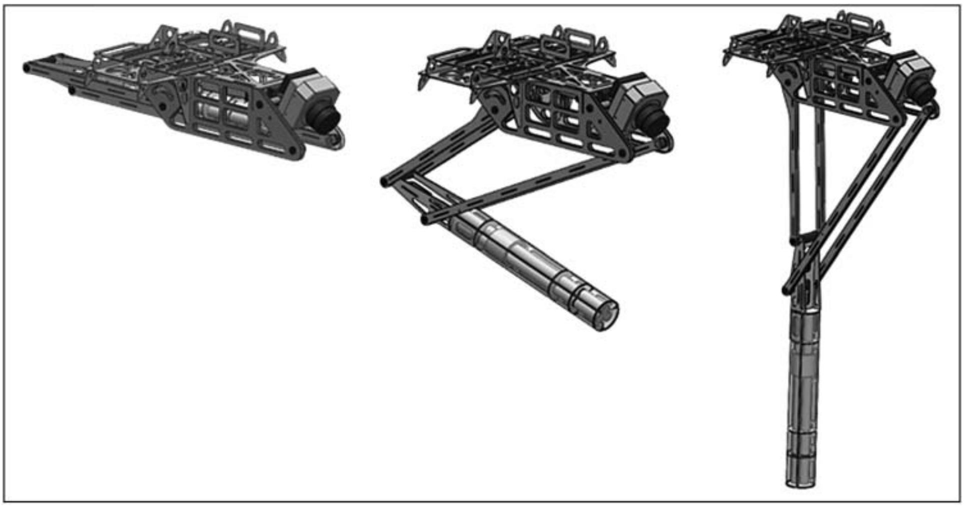

Figure 4. Avalanche beacon retractable system (left: completely retracted, middle: during deployment, right: completely deployed-working position).

can be processed and removed. Although no evidence of electromagnetic noise coming from carbon fibre propeller was noted, its contribution may be among the many other noise sources.

The adopted configuration requires the antenna to be installed on a retractable system so that it can be closed during take-off and landing and deployed in flight when the search operation starts. Figure 4 shows the avalanche beacon retractable system in three different positions; this payload is fixed between the legs of the UAV and stably installed on it also when stored in backpack. An actuator, controlled by the UAV, can set the sensitivity gain of the beacon in order to optimize the receiver signal to noise ratio.

3.2.2. Beacon signal processing

The typical audible (2 kHz) analog signal coming from the beacon is first adapted using an operational amplifier in terms of voltage range and impedance to the processing devices. As mentioned before, two different approaches were followed (see Figure 5).

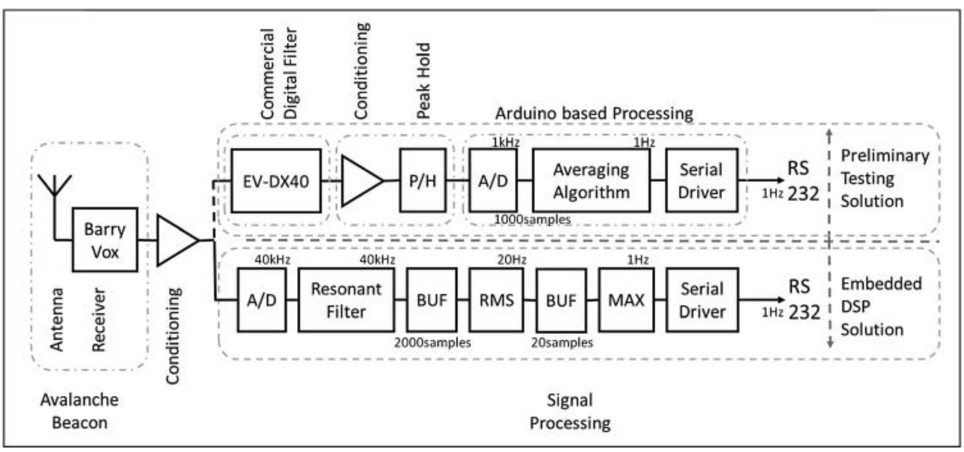

Figure 5. Scheme of the signal processing in the two presented hardware implementation.

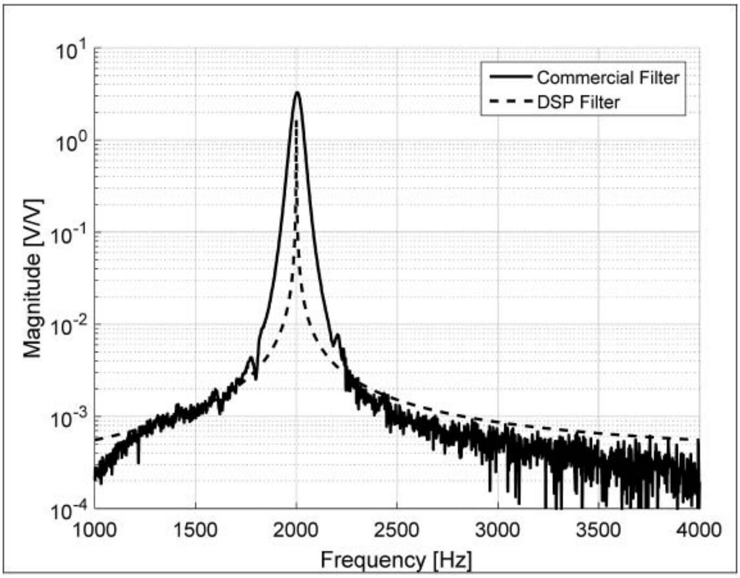

Figure 6. Comparison between the commercial filter transfer function and the DSP implemented.

In the preliminary testing solution (upper part of the signal processing blocks of Figure 5) the conditioned beacon signal is sent to ground by an analog audio transmitter. There it is band-pass filtered by means of a commercial audio digital filter ElectroVoice DX40. Figure 6 – continuous line shows the measured frequency response function of the filter. The purpose of the band-pass filter is to extract the beacon audible signal at 2 kHz from the background noise (frequencies lower than 1966 Hz and higher than 2040 Hz are attenuated according their frequencies). The filtered signal is then sent to a peak-hold analog circuit that transforms the 2 kHz bursts from the beacon into a rectangular wave whose high-level voltage is proportional to the strength of the input signal. An Arduino-based circuit converts this voltage into a digital value. The implemented algorithm takes the part of the signal whose amplitude is higher than the noise threshold, averages it, and updates the output once per second. This process allows for the conversion of the intermittent beacon signal to a digital value proportional to the signal strength. The computed value is sent to a PC to update the flight path. The transmission is performed using the available telemetry link through a serial protocol.

Even if the update of the flight plan is performed on the ground, the system has been designed to allow for the integration on the UAV of all data processing and flight management.

To remove all connections to the UAV, except a compulsory telemetry link used just for monitoring purpose, the embedded solution was developed. The beacon signal analysis is implemented (lower part of the signal processing blocks of Figure 5) on a TI DSP (Delfino 32bit floating point) board that acquires the conditioned signal with a sampling rate of 40 kHz; a resonant second order filter (Figure 6 – dashed lines) removes the frequencies components, out of 2 kHz range. This filter has been designed with comparable properties to the commercial one but with lower damping to improve the selectivity at 2 kHz. The filtered signal is buffered in blocks of 2000 samples. Due to the 40 kHz sampling frequency, these blocks are generated at 20 Hz, enough to capture the 0.1 s bursts generated by the transmitter. A serial connection sends the root mean square (RMS) value of each data block to the autopilot which uses it to trigger the various flight status.

In this process the presence or absence of the received signal is detected setting a proper threshold that has been set according to the background noise.

3.2.3. Flight integration

UAV flight must be completely autonomous including take-off, search operation and landing. As strict timing is the key factor, the flight parameters have been tuned to minimize wasted time. Preliminary operations such as path planning, sensors stabilization and similar are avoided from the operations that are set according to the following plan:

- At take-off, forward flying and beacon antenna deployment starts as soon the UAV reaches the defined terrain following altitude.
- Forward flight speed during GRID phase is set to a maximum of 4 m/s (best compromise for beacon first signal detection).
- Any pause at waypoints has been removed.
- Hovering over any reached waypoints (without pausing, but reducing the speed to avoid overshooting) has been preferred to fly-over, without speed reduction, to minimize flight distance and decrease times.
- During last tests heading is kept constant along all the flight to avoid waste of time for unnecessary turn-around manoeuvers (both in GRID and CROSS flight).

Similarly, all the preliminary ground procedure prior taking-off has been minimized:

- The UAV is removed from backpack, arms are deployed and battery is installed quickly.
- Fix GPS, and sensors calibration is loaded at the same time autopilots avionics initializes. The sensors do not need any specific calibration or zeroing procedure prior flight as correction table is loaded from autopilot calibration.
- Visual survey from the operator to identify obstacles in the search area.
- The mission is pre-programmed in the autopilot and just needs to be tuned with the avalanche parameters (size and orientation). No software mission programming is therefore needed before take-off.
- An optional ground station can be used to monitor the rescue mission.

All this allows for a quick deployment time from the arrival on the emergency site.

The avalanche area is not known in advance, so the pre-programmed flight parameters are tuned as follows:

- UAV is placed on the snow about 10 m from one of the lower corners of the avalanche. (This is not mandatory and it has been used during experimental validation to follow a standardized procedure; rescue mission can start directly from the take-off point or elsewhere, provided a little modification in the pre-programmed flight parameters with no impact in the mission time).
- UAV is pointed (heading) towards the lower (down-slope) edge of the avalanche: to acquire the target flight direction.
- A switch on the UAV sets the left/right hand position of the avalanche relative to the take-off and a potentiometer sets the approximatively length of the avalanche edge.
- Once the UAV is initialized, it acquires GPS lock, loads sensors thermal compensation, acquires heading and edge parameters and become ready to take-off.
- A button (or a trigger on the ground station) arms the take-off.

The autopilot conducts the flight autonomously, while the signal coming from the beacon receiver system can modify the flight path according to the rescue phase.

3.2.4. Terrain following

Avalanche areas are characterized by irregular slopes that have little to do with plane surfaces, so flying keeping a constant distance from the ground is very important to:

- avoid collisions with the terrain and its irregularities;
- maintain the antenna at a constant distance from the snow to avoid adding the variable of altitude in the measurement.

Although accurate, the standard barometric altitude measurement is not suitable due to its natural drift and because it requires the knowledge of the terrain model, usually not available with the required accuracy.

The terrain following capability that has been integrated on the UAV is based on a small size (40 × 40 × 20 mm) and weight (43 g), 905 nm wavelength laser distance sensor. Its 80 m range, 10 cm accuracy (typical) and 100 Hz update rate (as by MDL 2013) make it suitable for the flight mission. The original doubts about its functionality on snow were dissipated by experimental measurements made on a snow-covered slope; its performances in light fog do not degrade, but the fog, rain and snow effects have not yet been investigated in detail.

The laser sensor is rigidly fixed on the UAV so it changes its orientation as the attitude of the quadcopter changes. Typical attitude variation is usually inside $\pm 6^\circ$–7° in normal operation and can increase up to $\pm 15^\circ$ in case of strong wind. This affects the measurements with a 1% or 4%, resulting in about 5—20 cm deviation in the typical distance from ground during the mission, so comparable to the accuracy of the sensor.

3.2.5. GRID flight

After take-off the UAV climbs, in the meanwhile the beacon antenna is automatically deployed and the terrain following feature is activated bringing the UAV to an altitude of 5 m. This distance has been set to maximize the antenna effectiveness with a reasonable safety margin in case of sharp slope variations of the terrain. At this stage, the first phase 'GRID flight' is initiated (see Figure 7: solid black arrow).

The first leg is parallel to the front-edge of the avalanche with the length selected before the take-off. Once the leg is flown the UAV turns up-hill to perform the backward leg. Legs distance is 10 m, which optimizes the beacon sensing performances.

This way of flying continues until the first signal coming from the buried beacon is acquired; at this stage the following 'CROSS flight' is initiated.

3.2.6. CROSS flight

The 'CROSS flight' starts as soon the first signal from the transmitter is detected. With reference to Figure 7: thick arrow, during this phase the UAV performs automatically the following operations:

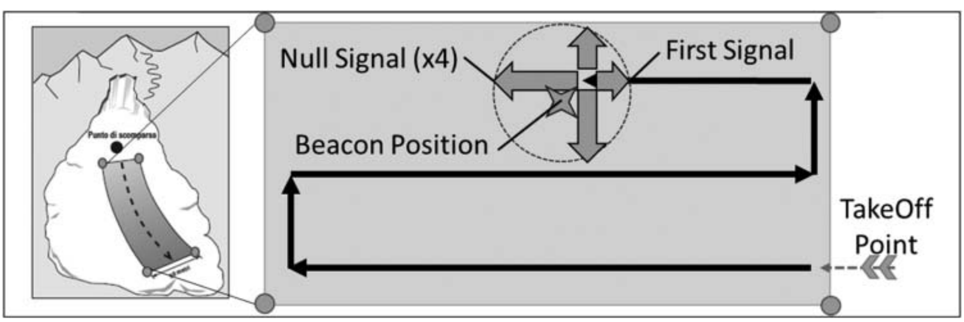

Figure 7. Search scheme: solid arrow – GRID flight, thick arrow – CROSS flight.

- Forward flight until the beacon signal is lost (below a selected threshold); at this stage, the current GPS position is stored; the flight segment continues to ensure avoiding false null signal detection (common in analog avalanche beacon); in the case, the GPS position is updated.
- Backward flight (same heading, opposite direction) until the beacon signal is found again and continue flying until the signal is lost. Stores the second GPS point.
- Autopilot computes the midpoint between the two GPS acquired location and flies to it.
- Turn 90° and fly the following part of the cross to identify the next two GPS point as vertex of the 'cross.'
- Autopilot computes the midpoint between the two GPS acquired location and flies to it.

This point should be the placed with the highest signal strength corresponding to the buried transmitting beacon.

To increase reliability, an algorithm evaluates the quality of the survey. It considers the presence of false signal and how the signals decrease; if this index is considered low the UAV can perform a second cross that should grant a better identification performance.

3.2.7. Autonomous landing

The UAV lands on the identified burying point. Alternatively, it can communicate the position to the rescue team, land in a different area or continue the search (with GRID flight) mission finding other buried persons.

Automatic landing is performed using the laser altimeter; the altitude is reduced keeping a constant identified GPS, only latitude and longitude, position. Above to 2 m from ground the descend speed is 1.5 m/s, below 2 m it is decreased to 0.2 m/s. When the altitude is lower than 0.5 m the altitude loop is disengaged and the throttle is reduced with a constant slope. This procedure minimizes landing time, neglect ground effects and results in a safe landing also on non-homogeneous terrain.

4. Results and considerations

A test campaign, both at a testing facility and in mountain environment (altitude from 300 m ASL (aAbove sea level) and 2600 m ASL) were used to validate and guide the design described in the previous paragraphs.

A first set of tests were used to set the control parameters to guarantee the UAV stability and its flight performances with the antenna-receiver payload. The functionality of the beacon receiver and all the signal processing chain was tested flying over a transmitting beacon. This phase was also used to set thresholds and measure achievable search ranges. The final configuration of the UAV prototype had a total weight of 3.5 kg (including batteries and all subsystems), as detailed in Table 2.

A sequence of flights was performed in a mountain environment to validate the terrain following performances with different slopes. Figure 8-left shows the terrain profile with the actual UAV altitude and the altitude on a high slopes (about 30%); in this case the error is usually less than 1.5 m. Similarly, Figure 8-right shows the terrain following behaviour in a more realistic case; data was acquired during a GRID phase on a typical avalanche area, and an error of about 0.75 m was observed with a sloped of about 15%. During this test, particular care was devoted to evaluate GPS

Table 2. UAV subsystem masses in the final prototype configuration.

Subsystem	Mass (g)
UAV (w/o battery)	2100
Battery (LiPo 6s 4600 mAh)	580
Laser altimeter (MDL80)	55
IR camera (FLIR Tau2 + Lens)	75
Beacon retractable system (including antenna, receiver, processing)	680
Total mass	3490

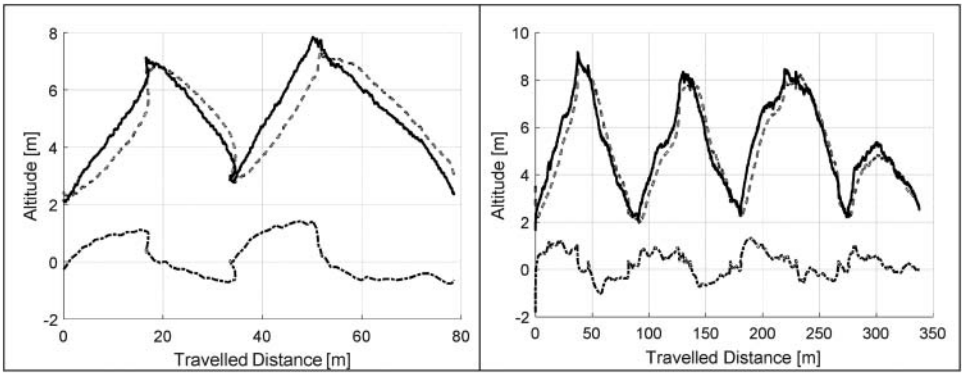

Figure 8. Terrain following performances – solid line: terrain profile, dashed line: flying altitude reported to ground (current altitude – imposed distance (5 m)), dash-dot line: absolute error.

Table 3. UAV power consumption (W) and relative flight endurance at different sea level altitude and take-off mass (endurance is computed considering a safety margin on battery capacity of 10%).

S.L. altitude T.O. mass (kg)	300 m Power (W)	2200 m Endurance (min)	300 m Power (W)	2200 m Endurance (min)
2.5	310	19.8	315	19.5
3.0	360	17.0	420	14.6
3.5	460	13.3	550	11.1

performances on snow-covered fields. While multipath effect on snow can result in degraded GPS performances, according to the experiments, no issue has been noted. Probably the use of GPS together with IMU sensor for navigation and the relative distance from snow mitigates the problem.

Data regarding the UAV power consumptions was acquired flying with different payloads at various altitudes, and is summarized in Table 3, besides the estimation of flight endurance considering a safety margin of 10% on the battery capacity.

4.1. Rescue mission flight and performance identification

The system functionality has been intensively tested simulating a real rescue mission.

Search time and flight performances were optimized by tuning control and navigation loop to increase accuracy and robustness to wind and external influences. All optimization is aimed to reduce wasted time during the flight mission; to this end, an experimental trade-off enabled us to reduce times by about 30% without decreasing any flight performances, acting on turn-time, hover stop and flight speed.

Experiments were performed first on a flat terrain and then in snow-covered slopes. They were performed on a simulated mountain rescue mission (at sea level and then at 1900 m) on snow with -3 °C air temperature and light gusty wind condition (about 3–5m /s).

Figure 9-left shows the GRID flight phase. First, signal is detected close to the middle of the third leg (F: cross, on the Figure 9-left). The 0,0 coordinate (square, on the Figure 9-left) represents the lower corner of the avalanche. The selected leg length is about 60 m and the avalanche is supposed to be on the left side of the UAV take-off point (TO: upward-pointing triangle, on the Figure 9-left). Position accuracy during legs navigation in no-wind condition is usually less than 1 m, the value increases to about 2 m especially in case of wind gust.

Figure 9-right shows the CROSS flight in relative coordinates with the origin located where the first signal is detected (point F, Figure 9-left). The UAV flies 15 m forward before the signal is lower than the threshold (A cross, on the Figure 9-right); at this point it stops and inverts the flight

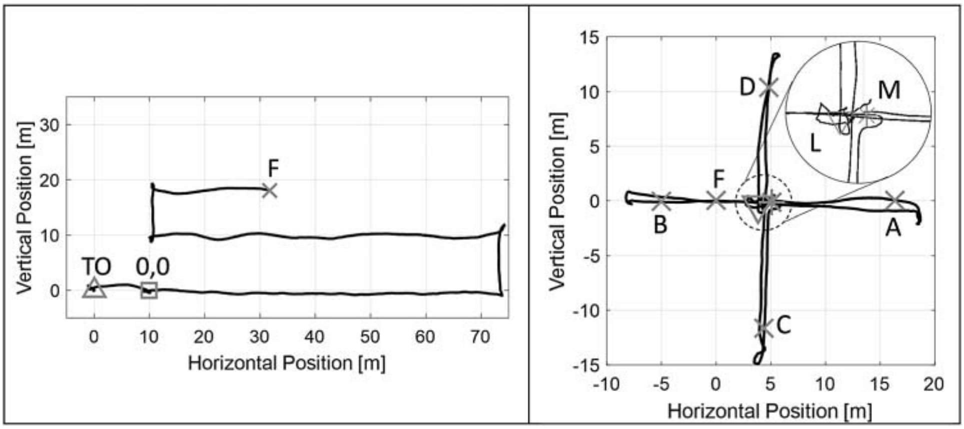

Figure 9. Acquired GRID (left) and CROSS (right) flight path.

direction. On the way back it re-acquires the signal and loses it again in B (cross). The midpoint is computed in M. After the UAV has flown to M (asterisk) it repeats the same procedure in orthogonal direction; points C (cross) and D (cross) represent the signal losses. Midpoint between them is the supposed SCB position, where the UAV lands (L: downward-pointing triangle).

Point B is behind the point F because during the GRID phase the flight speed is set to 4 m/s, and it is decreased to 2 m/s during CROSS to improve searching accuracy.

Navigation accuracy during this phase is almost the same as that during GRID.

Typically buried identification accuracy is less than 1 m. In this specific case is 0.6 m.

4.2. Rescue mission times and comparison

A time rehearsal campaign was performed to evaluate the time needed for the UAV to accomplish the mission. Assuming that at the beginning the system is in a backpack located in the emergency area, the reference mission can be split in four phases:

(1) Pre-flight: from unpacking to a complete take-off
(2) GRID flight (coarse search in traditional search)
(3) CROSS flight (fine search in traditional search)
(4) Landing (or marking)

Pre-flight operation, in typical condition, takes less than 2 min, while landing from operative altitude takes typically 10 s; these can be considered constant times during missions. Table 4 reports the detailed timing for each operation.

Table 4. Times required for UAV pre-flight operation and for landing.

		Start (s)	Duration (s)]	Elapsed (s)
Pre-flight	Unpacking	0	10	10
	Arms deployment	10	15	25
	Battery installation	10	10	20
	Closing	20	5	25
	Power ON	25	2	27
	Initialization (max)	27	50	77
	GPS fix and ready (typical)	77	30	107
	Motor ramp and vib check	107	8	115
	T.O. to 5 m	115	8	123
Landing	(Typical)	–	10	–

GRID time depend of the flown distance before first signal detection, while CROSS flight is almost constant as usually the arms of the cross have an average length of about 10 m.

Assuming the UAV search started at the same time as the traditional man-based method, the comparison shows an advantage for the UAV solution especially in the GRID phase where the UAV flying speed is faster (4 m/s) than walking (1 m/s (Knapik 1996; Connolly 2002)).

Assuming that the rescuer and UAV follow the same search methodology, during CROSS phase times and speeds are comparable. During this phase UAV average speed is comparable to walking because the stops to invert motion.

Considering the new multi-antenna beacons that guide the rescuer directly to the buried person after the first signal detection, search time can be reduced. These solutions can also be implemented on the UAV with similar advantages.

5. Conclusion

The present paper shows the results of the design, construction and validation of an UAV-based system for mountain rescue activities (Figure 10) based on avalanche beacon. The effectiveness of visual/thermal survey has also been evaluated.

The system is based on a commercial UAV that has been identified in the preliminary phases of the project to allow the integration of the avalanche beacon receiver and a FLIR IR camera.

The avalanche beacon has been installed with a retractable system to minimize UAV disturbance to the receiver. The beacon signal is processed using two different hardware implementations: the first, suitable for developing and testing, involves signal processing and the automatics flight re-planning on ground, the second, more integrated, is designed to allow the fully autonomous operation of the UAV with no need for ground devices.

The UAV is capable of a complete autonomous flight, without needing pre-programming. Its mission parameters are set according to the searching area in a pre-flight phase. Specific features

Figure 10. UAV during a search and rescue mission with avalanche beacon antenna deployed.

have been developed for the rescue mission such as: terrain following (using a laser altimeter), interaction with avalanche beacon signal and automatic in-flight reprogramming.

To compare UAV performance to standard search by humans, the rescue mission approach is based on a well-established avalanche beacon search practice. The UAV is capable of flying a GRID up to the first identification of the beacon signal and then switches to a CROSS profile for a fine identification of the buried individual: at this point it can communicate the position of the SCB person and/or land in the identified point or continue the search phase.

Several experiments were performed both at testing facilities and in the real mountain environment. The results show the following:

- Distance to ground, while flying with the terrain following capability, is usually within 1 m accuracy.
- Navigation accuracy, even in real (wind up to 5 m/s temperature in the range of −10 to 25 °C) conditions, is typically within 2 m.
- Achieved localization accuracy is less than 1 m.

This allows for a quick search operation compared to traditional methods. The best performances were obtained when wide areas need to be surveyed. An additional benefit is that the rescue team needs to move on the avalanche just for extraction and rescue operation minimizing the risk related to secondary avalanches.

The proposed solution can become more effective if the system is integrated in a structured rescue procedure as, for instance, bringing the UAV on the rescue helicopter (and in case dropping from it) or with some UAV permanently located on the ski area that can be triggered upon emergency (most suitable for sky resort application).

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