

UAVs for Humanitarian Missions: Autonomy and Reliability

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Abstract—Information plays a key role in natural disaster crisis management and relief. A new generation of lightweight UAVs may help improve the situational awareness and assessment. They may first of all relieve rescue teams from time-consuming data collection tasks. At the same time, those UAVs may assist research operations through a more insightful and automated guidance thanks to advanced sensing capabilities. In order to achieve this vision, two challenges must be addressed though. The first one is to achieve a sufficient autonomy for such vehicles, both in terms of navigation and of interpretation of the data sensed. The second one relates to the reliability of the UAV with respect to accidental (safety) or malicious (security) risks. This paper first discusses the potential of UAV assistance in several humanitarian scenarios, as well as potential problems in such situations. The question of autonomy is then addressed. Finally, a secure embedded UAV architecture that relies on cryptographic protocols and on specific hardware capabilities is sketched.

Keywords—UAV; drones; 3D perception; security; safety

I. INTRODUCTION

According to Guhar-Sapir and Hoyois [1], in 2012, naturally triggered disasters (earthquakes, landslides, and severe weather, such as tropical cyclones, severe storms, floods) killed a total of 9,655 people, and 124.5 million people become victims, worldwide. Although those numbers were well below the 2002-2011 annual averages (107,000 people killed and 268 million victims), economic damages did show an increase to above-average levels (143 billion US dollars).

When a natural disaster occurs in a populated area, it is mandatory to organize disaster management operations quickly and effectively in order to assist the population, to reduce the number of victims, and to mitigate the economic consequences [1], [2], [3], [4]. A non-optimal organization causes supplementary losses and delays in resuming the situation to normal¹.

Regardless of community size or the nature of the disaster, local government leaders are responsible for overseeing all three phases of the disaster-management cycle: pre-disaster, response, and post-disaster. Emergency management itself starts both with search and rescue, and then with the stabilisation of the overall disaster situation.

At any time, the rescue teams need immediate and relevant information concerning the situations they have to face:

disaster evolution, surviving persons, critical zones, access to refugee camps, spread assistance tools, etc. The required information is provided by a comprehensive data handling system, called a Geographical Information System (GIS), fed with data generally produced by organizations and space agencies involved in the International Charter “Space and Major Disasters”.

As explained in [3], new approaches and the use of new technologies are required for a more efficient risk management, before, during, and after a potential crisis. Every specific action at each step of the crisis must be specifically taken into account. For that purpose, new dedicated tools and methodologies are required to better handle crisis situations.

We present in this paper a few applications for which a new generation of unmanned aerial vehicles (UAVs), also termed drones, may improve the toolbox of response teams. In particular, we discuss how compact and lightweight aerial vehicles, which are rather inexpensive and flexible to operate in comparison with traditional aircrafts and satellites, may help extend the reach of rescue teams and enable a more systematic exploration of their surroundings. We also discuss the important challenges that must be addressed in terms of navigation and detection autonomy, as well as reliability in terms of safety and security, in order to enable the seamless use of such UAVs by non-experts.

II. POTENTIAL APPLICATIONS OF UAVS

A. Communications and coordination

One of the first actions to be taken in any search and rescue operation is to set up a disaster cell for coordination. For major risks, this includes national ministries, civil defense, regional and local administrations, nongovernmental administrations involved in disaster management, experts, crisis staffs, a command chain, an information chain, etc.

During such an event, maintaining a communication link with the various actors of the response on the one hand and with victims on the other hand is crucial. Unfortunately, when the communication infrastructure has been damaged, rescue teams rely essentially on radios or satellite communications. This link remains essential even in the case of non-catastrophic circumstances, like for instance a major black-out in a network (electricity, water, etc.).

¹<http://www.un-spider.org/>

UAVs might extend the communication range available as they may be deployed as mobile radio relays. UAVs may also convey messages in a disruption tolerant network (DTN) fashion, during their normal operations, typically between the actors involved. Of course, the operation of a UAV generates its own communication needs, and an UAV control center must be operated either by the disaster cell or by mobile units on site. The operation of such a center should be as seamless and intuitive as possible, which can only be made possible by rendering the UAV navigation autonomous.

Data sensing results have to be communicated as they are produced, and will serve for the coordination of relief operations. In this sense, the UAV should also be autonomous in deciding which data to preprocess and to communicate in order to establish operational priorities.

Communications between a control center and UAVs and between UAVs must be secured to prevent any unwanted interferences (pranksters and vandals, for instance), to prevent unauthorized access to the sensitive data sensed to third parties, as explained below, and possibly to detect communication anomalies (crash of an UAV, radio jamming, etc.).

B. Terrain-oriented reconnaissance

The detection and the monitoring of the impact of natural disasters on terrain are mainly performed by space borne and air borne relying on radio and optical instruments. Due to limitations in the time window observation attached to optical instruments (i.e. no observation at night or in presence of cloud cover), radio observations are available 24/7 and relatively insensitive to atmospheric conditions: these are therefore particularly useful during the "Response phase" of the disaster management cycle when information must be delivered to the disaster cell with a as short as possible delay [5], [6], [7].

UAVs may bring significant improvements with respect to those issues. They can be easily equipped with various kinds of sensors in addition to optical ones depending on their potential mission. Their altitude makes it easy to observe below a cloud cover. Finally, search and rescue teams may carry UAVs and deploy them according to the required need on site, for instance to explore some flooded area in order to find a practicable path to reach the victims, or a ruined building. In this respect, UAVs extend the exploration range of rescue teams while at the same time improving their safety in areas that may reveal dangerous for their own safety. The senseFly UAV has for instance demonstrated the automated mapping capabilities of small drones and how they could improve the lives of victims in the aftermath of the Haiti 2010 earthquake, by enabling the authorities to quickly draw maps of devastated areas [8].

Developing and integrating autonomy features into the UAV is key to this application. Indeed, the UAV is likely to be in situations where it could be unable to communicate with the control center, either sporadically due to interferences, or for extended periods of time if it explores terrain behind obstacles or beyond coverage of any radio relay. Depending on the realtime requirements, communications capabilities, and complexity of the sensors deployed, the data sensed will be either processed on-board or transmitted to the control center to be interpreted and dispatched to operational units. In any case, autonomy is also essential for a non-expert usage of the UAV

locally and appropriate navigation and data fusion algorithms have to be developed. Autonomy does not mean that the UAV will not be controlled remotely, for instance in order to zoom in on some scenes that would be of interest to rescue teams even if it were not considered so by the UAV itself.

The access to the data sensed by the UAV must be managed by the control center. This should be in effect during in-flight communications as well as in case of a crash for the data stored within the UAV. In effect, the data sensed may be valuable commercially or may have political implications. The deployment of UAVs should not be diverted by third parties and ultimately result in hampering the relief operations.

C. Search operations

Similarly to terrain reconnaissance, satellites and aircrafts are currently used to locate and count the victims of natural disasters, with equally problematic liabilities in terms of weather and diurnal conditions, as well as availability.

Autonomy also plays a key role in this application, but specific features have to be developed in order to look for victims. An appropriate range of detectors will have to be combined in order to distinguish between human beings and inanimate objects, especially when victims are buried under ruins and cannot be detected optically. The UAV should also be able to discriminate victims from rescue teams. Algorithms finally have to be adapted to the detection and monitoring of victims and groups of victims in order to anticipate their movements and to determine the medical treatment they may require.

Safety issues are a major concern in this application. The low altitude and autonomy of navigation of a UAV may potentially cause injuries to nearby victims or rescuers in case of a crash for instance. This means that UAVs must encompass this dimension from the very early phases of their design and integrate safety mechanisms in order to handle possible mechanical, hardware and software failures. It is for instance possible to operate the UAV in a degraded mode with less motors in order to land safely or to fire a parachute to reduce the impact speed.

The security of the data sensed and stored onboard UAVs may be especially sensitive with respect to victims' privacy. For instance, there have been situations in the past where pictures of recognizable victims have made the headlines without their agreement.

The deployment of UAVs for such applications will also bring up societal challenges. Indeed, the apparition of a UAV may be terrifying to an unprepared victim, which might reduce the effectiveness of the detection operations. In contrast, victims may not notice UAVs flying at a high altitude and therefore they may fail to signal their position, as they would try to do for an aircraft. New standards will probably have to be defined in this respect.

III. DATA SENSING AND PROCESSING

Previous work with specialists from the disasters intervention (French "Protection Civile", MSF², ICRC³, etc.) allowed

²Médecins Sans Frontières

³International Committee of the Red Cross

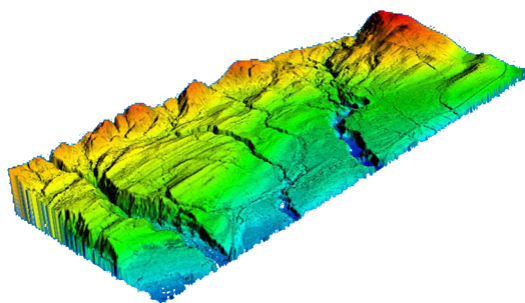


Figure 1. Terrain mapping with a LIDAR

us to formalize three primordial requirements for rescue teams among the set of applications described in the previous section.

The main goal is to assist victims in the shortest possible time. To reach this objective, it is necessary (1) to detect the people impacted by the event, but also (2) to identify the possible accesses (e.g., safe roads, paths, practicable terrain) to the disaster area and to the victims. These operations are not instantaneous, and it is also necessary (3) to perform a continuous assessment of the evolution of the situation in the impacted area. In this phase, it is notably important to inform and reassure victims and to ensure and avoid that people do not get lost again because they would move away. The effectiveness of these operations depends on the speed and accuracy at which they can be carried out.

We discuss in the following three classes of payloads and the associated data processing capabilities that can be put onboard UAVs in order to illustrate the interest of this technology for addressing the above challenges.

A. Systematic terrain scan

A first class of UAV data sensing payload relates to the systematic coverage of some terrain in order to perform the "rapid mapping" of the search zone and to establish an emergency map. Emergency typically requires monitoring a situation over time and more detailed analysis using very-high resolution data. Using such information, it is easy to produce in a few passes a thematic map appropriate for relief operations. The interest of these maps for decision support is very dependent to the sensor used. For example, the "light detection and ranging" (LIDAR) detectors use laser pulses to generate large amounts of data about the physical layout of terrain and landscape features. All varieties of LIDAR operate using the same basic principle. The instrument fires rapid pulses of light (laser pulses) at the landscape and a sensor mounted on the instrument measures the amount of time taken for each light pulse to bounce back. Because light moves at a constant and known speed, the instrument can then calculate the distance between itself and the target with a high accuracy. By rapidly repeating the process, the instrument builds up a complex "picture" of the terrain it is measuring. With this method, we can obtain Digital Elevation Models (DEM) allowing a large set of ground analysis (see Figure 1).

The terrain coverage task is a new feature offered very flexibly by the use of UAVs. This basic building block also

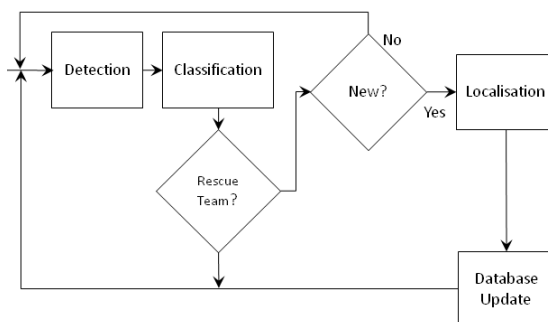


Figure 2. Detection cycle

offers a strong interest to deploy more complex payloads and processing capabilities as explained in the next two sections.

B. Autonomous detection and classification

A second class of data sensing payloads aims at the detection of victims and their classification (see Figure 2). For a drone, this means advanced people detection capabilities. Simple people detection (e.g., silhouette based) is not sufficient. Indeed, the quantification is an important information for organizations that manage the disaster. It allows the optimization of logistical aspects (tents, food, medical staff, etc.). It is therefore necessary, upon the detection, to implement a phase of recognition (signature) in order to count each victim only once. Another related problem is the discrimination between victims and members of a relief team.

An UAV will for instance have to identify groups of disabled persons, and determine whether they are adults or children. That distinction makes sense because the support that rescue teams have to provide strongly differs in the two cases. Such a triage must be compliant with international and local ethical policies. Following or tracking a specific group might also be of interest for measuring their velocity and forecasting their expected position in a near future.

C. Data fusion

Data fusion between optical (visible and IR) and radar data can also produce non conventional data allowing the extraction of pertinent information for decision support (see Figure 3).

Another non conventional approach has been suggested for improving the search for buried victims. The idea is to look for electromagnetic emissions emanating from their mobile phones or other connected objects, the objective being to identify the rubble pile under which rescue teams are most likely to find victims. Rescue teams should be guided to the most probable locations where to go and search for victims. The location of personal connected objects might be envisioned as a new means to detect victims buried in the ruins after an earthquake. In particular, UAVs may embed several printed antennas whose goal would be to trace the source of emissions of such connected objects. This objective highlights the need for a new airborne solution to detect and map the position of people, sometimes even buried victims of disaster. The main idea is to make an image of the ground using an antenna, carried by a drone flying at a very low altitude.

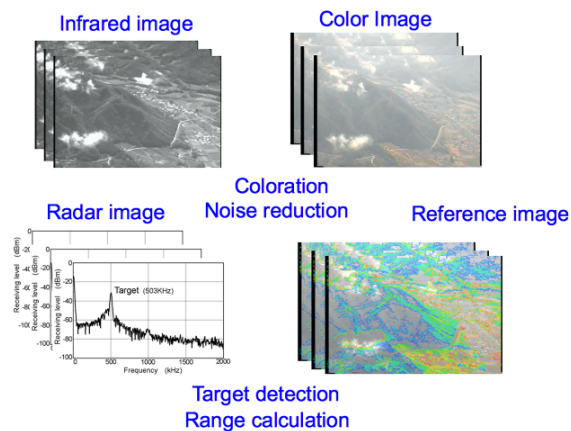


Figure 3. Data fusion out of optical, radar, and infrared sensors

This is now possible thanks to the increase in the processing power of processors, to the lower energy consumption of active components including RF, and to the availability of larger storage capacities in a smaller volume, which is a significant factor for onboard equipments. Embedded sensors will have multi-band capabilities, so as to consider all radiation sources. They will also feature a strong directivity in order to precisely target the source of an emission. Finally, they have to be low weight. Sensors will be used for UAV navigation as well as for terrain mapping and victim detection.

Two approaches can be adopted. The "passive" approach consists in designing an antenna whose directivity, gain adjustment weight performance will be optimal according to the available weight and space onboard the UAV. The drone will thus be able to detect an EM emission in vertical position. It can then record the location of the source of E.M. emissions and transmit it to the control center. In contrast, the "active" approach, consist in covering, in a single pass, a wider geographical area. To do so, active electronics can scan an angular area around the vertical to the aircraft, in the plane perpendicular to its displacement. In case of a detection, the UAV will then forward its current coordinates as well as the angle of signal arrival to the PC. This can be likened to 2D synthetic aperture antennas though with a purely listening approach. Supporting those scenarios obviously requires UAVs to fly autonomously according to their target mission.

IV. HUMANITARIAN UAVS: ARCHITECTURAL ELEMENTS

Due to the conditions of search and relief efforts, rescue teams can only afford to carry lightweight and compact UAVs. Most industrial UAVs, which come with a lot of support systems, do not fit these requirements. Humanitarian UAVs will therefore have to rely on equipment that has initially been developed for model flight. We discuss in this section the architecture of existing UAVs and our proposal to evolve it for the tasks discussed in the previous section.

A. Existing UAV equipment

Figure 4 presents the architecture generally used in current model flight UAVs. A flight controller performs an automated stabilization task that will smooth the actions requested by

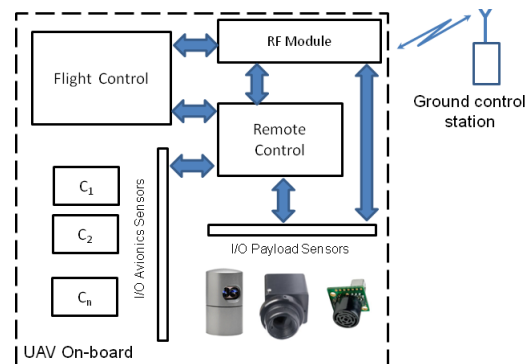


Figure 4. Current UAV architecture

a pilot through a remote control. Despite their compactness, those UAVs can lift up to a few kilograms of payload sensors.

The UAV often provides an optical sensor based on one or several camera. In addition to control data which are sent through the remote control radio link, payload sensor data are generally sent back to the pilot through a dedicated radio (RF) module. These systems are sometimes even used for first-person view (FPV) flight and may also be complemented with telemetry data.

Some UAVs also feature an embryonic form of autonomous navigation through GPS waypoint routing. Industrials have also caught up, and started developing autonomous UAVs in this class, like the senseFly UAV [8]. However they still lack a certain number of autonomy features in the humanitarian context and their architecture does not address reliability requirements.

B. Proposed UAV architecture

Figure 5 presents the architecture that we currently develop. A flight controller implements an autonomous control of the system. This relates to the actions to be taken in normal flight conditions. This involves mission planning through the determination of points of interest, of the type of sensors necessary to acquire data and of their settings, and so on.

A device dedicated to emergency situations may take over the flight controller if the UAV goes out of its flight envelope. For example, abrupt changes of environmental conditions, partial loss of buoyancy, a significant decrease of electrical energy, etc. may require triggering an immediate landing, or even the firing of the emergency parachute.

The remote control system allows an update of the mission and enables a human operator to resume a manual mode of operation of the UAV. The Energy system is vested in the management and the optimization of the energy capacity. It performs a continuous evaluation of the 'point of no return' depending on the conditions of the mission. It may suggest altering the flight plan (return to the point of departure, emergency landing, etc.) in order to remain in a range of flying course. The Safe and Secure procedures are intended to ensure the safety and security of the UAV, both in terms of dependability and robustness to the various attacks it may undergo. Such situations may result from voluntary attacks (attempts of diversion of the drone or its information) or environmental conditions (interferences due to natural phenomena,

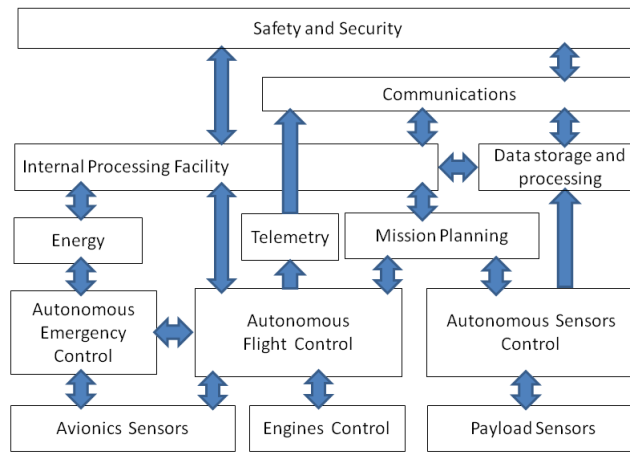


Figure 5. Proposed UAV architecture

like for example space weather, or the occurrence of heavy ions). The communications subsystem is the link between the drone and the ground control. It enables remote control as well as the access to the payload data harvested by mission-oriented sensors and the transmission of telemetry data.

C. Communication technologies

The communication system must be operational even in hostile environments, in particular, it must withstand interferences. The communication range may be up to a few tens of kilometers, e.g., for damage assessment or terrain reconnaissance, but is more typically one or two kilometers, e.g., for search and rescue operations. The communication channel must support (i) control-command, e.g., a few kbytes per second, (ii) data sensed by the UAV, for which communication bandwidth strongly depends on embedded sensors' characteristics, on the mission profile, and on the computation strategy, and (iii), real-time Remote video, e.g., up to one Mbits/s.

Ground control stations can be equipped with spatially spread antenna networks so as to better handle signal loss due to terrain and building obstacles. Used frequencies are the classical 2-5 GHz band e.g., UHF and SHF. Frequency configuration must be easy to avoid interfering with other equipments.

V. AUTONOMY

For every scenario that we described in previous sections, UAVs need to be almost fully autonomous in their mission, and subsequently in their flight control (autonomous navigation). Operating the UAV must be accessible to non-expert in flight control or in robotics. It must not be an additional burden on rescue teams in operation. In particular, the autonomous navigation must be able to evolve in disaster areas which terrain topography can be highly complex. This includes the capacity to autonomously fly close to the ground while identifying obstacles. The rest of this section focuses on two issues: (i) technologies for achieving autonomous navigation, and (ii) technologies for identifying victims. Contributions in both domains were developed by our team in the scope of the *drone4u* project [9].

A. Autonomous navigation

Autonomous navigation techniques vary depending on the environment of the UAV. Indoor navigation is globally easier than outdoor. Difficulties attached to the weather like rain and wind do not exist. Moreover, the UAV might be aware of the map of the building it explores and of the nature of the objects it could encounter inside of it. As of today, we can also envisage the use of RGB-D cameras, which is almost impossible outdoor. The main difficulties of indoor navigation lie in potential collisions with people, doors, as well as the limited space for navigation.

In this context, the navigation requires an onboard intelligence. It should notably be able to fly close to the ground - the latter being potentially chaotic - while acknowledging automatically the obstacles in its trajectory, and with minimal or no action from the UAV operator. In previous works we provided autonomous navigation features to UAVs relying on both (i) the definition and implementation of special flight maneuvers (advanced control) and (ii) the definition and implementation of image analysis algorithms in order to reconstruct the 3D environment or to track information, objects, or people [10], [11].

Two techniques have been defined for 3D perception. These techniques have been introduced so as to reconstruct the 3D environment of the UAV using only one front camera.

- **Sparse 3D reconstruction** may be used continuously during regular flight and therefore is our preferred method of perception. It usually yields the spatial locations of a few hundred distinct image points, as depicted in Figures 6 and 7. The accuracy largely depends on the UAV motion: vertical and sideways movements are particularly beneficial: this explains our associated control strategy superimposes an oscillation in those directions, hereby creating a corkscrew-shaped flight trajectory (see [12]).
- **Dense 3D reconstruction** can alternatively provide an estimated distance for most pixels of an image, but in return requires exclusive flight control to virtually create a vertical stereo camera through a change in

altitude (see Figure 8). Because regular flight needs to be interrupted for this maneuver, results are dense in space but sparse in time.

More information on those two techniques are thoroughly explained in [10].

B. Autonomous victim detection

One important matter in relief operations are the human beings suffering from the disaster. We propose the following techniques in order to correctly identify victims. Two levels of identification have to be attained, for which objectives are clearly different.

Identifying individual victims. The main issues are to be able to get the precise location of individuals and to follow them. Thus, when identifying a person, the first task to perform is to evaluate whether that person was already met in the past, or not. The path of individual shall thus be stored (id, position, time). Using those information, and according to the disaster context, movement can be classified as normal or suspect (wrong direction for reaching safety facilities, overly slow speed, etc.) and thus help adapt the equipment or determine priorities the rescue teams.

Identifying groups of victims. In the case of a group, the main issue is to evaluate its density, the global movement, and its evolution in terms of the number of individuals being part of the group. This could be achieved by reusing what Dantcheva et al. proposed in [14]. This work typically focuses on the identification of the size of persons and colors of their clothes in order to establish a visual signature, and thus being able to track that given group.

Underlying image processing techniques are quite well-known, and originate from the video surveillance domain: the histogram of gradient are usual algorithms for detection, the bounding box and color histogram algorithms are the ones used for people tracking. Those algorithms have not yet been evaluated in the scope of UAVs, and will probably have to be adapted to the UAV context.

VI. RELIABILITY: SAFETY AND SECURITY

Legal and ethical constraints arise out of potential risks incurred by the use of a UAV with respect to both victims and rescuers. For instance, a UAV crash may cause damages and harm people; as another example, privacy requires that the release of any footage of a disaster be controlled. Satisfying these constraints requires taking into account the risks linked with fault-tolerance (like for instance in case of the violation of realtime deadlines of safety-critical tasks) and security (sensed data piracy, UAV hijacking, etc.) and to prevent them with appropriate countermeasures. Mitigating or preventing those risks involves the introduction of multiple safety and security mechanisms into components as well as within the overall architectural design, which we detail per domain below.

A. Communications

Securing communications will require message secrecy in the first place in order to prevent unauthorized access to the sensed data or preprocessed sensed data sent from the UAV to

the control center. The data stored within the UAV will also have to be protected in order to prevent their exploitation if an UAV is hijacked for some reason. These two objectives will be implemented simultaneously through content encryption.

Additionally, the source of messages (UAV or control center) will have to be authenticated, and the integrity of messages will have to be verified, in order to prevent individuals from:

- injecting bogus data into the system and for instance obtaining some information from the rescue operations;
- injecting fake commands and taking control of the UAV or fraudulently accessing stored data. Such attacks may result in serious risks with respect to flight safety for instance.

Since most communications will rely on different existing radio-based communication modules, those security mechanisms will likely have to be retrofitted at an adaptation layer interfacing the communications functionalities. The implementation of security countermeasures may also involve modifications to the UAV remote control in order to authenticate the commands transmitted to the UAV when controlled by a pilot.

The availability of an autonomous navigation system of course also addresses the difficult communication conditions that are to be expected (frequent disruptions) between the UAV and the control center. Such disruptions will notably be due to the low altitude of the UAV and obstacles. Those conditions will also require frequent resynchronizations between the UAV and the control center with respect to the cryptographic algorithm and will influence the selection of appropriate primitives.

B. Plausibility checks

A common way to ensure that a sensor (navigation sensor or payload sensor) has not failed or that its data have not been corrupted by an attacker is to perform a plausibility check. Those checks can be done on sensor data in isolation. Many embedded functions also rely on the data produced by several sensors, and checks will consist in ensuring their consistency. Typically, the stabilization system relies on data issued from the gyroscope, from the altimeter, etc. Such a function must be used in our UAV architecture to improve both the safety of critical function and to limit the impact of attacks.

C. Security architecture

The UAV architecture diagram in Figure 5 already depicts a security module that will be in charge of performing all cryptographic operations over communications as discussed above.

In addition to the diverse functions assured by this component, one particularly important objective will be to enforce an effective separation between safety-critical navigation functions and the other subsystems of the UAV. One particularly critical subsystem comprises communication-related components, which might potentially be affected by security vulnerabilities and that are open to malicious injections. Three separate information flows can clearly be identified on Figure 5, namely payload sensor data that are to be stored in the UAV, (pre)processed and accessed by rescue teams (or be

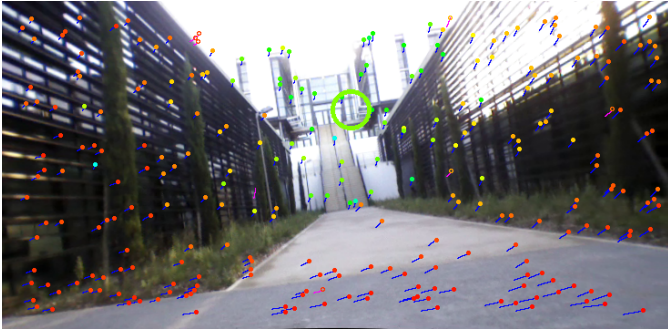


Figure 6. Sparse 3D reconstructions: Blue/purple lines show optical flow vectors respectively consistent/conflicting with the camera's motion. The color of a point depicts its longitudinal distance – red indicates 1 m and below, cyan 10 m and above. A larger green circle marks the tentative flight direction.

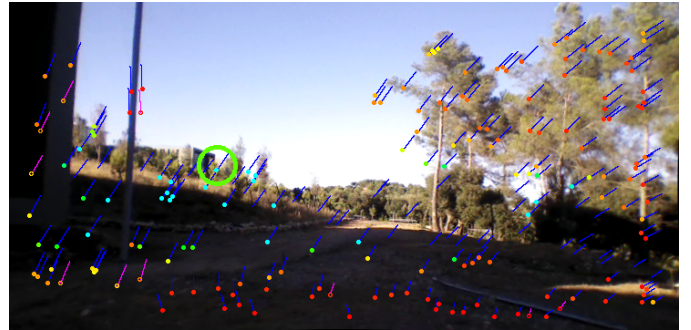


Figure 7. Imperfect sparse 3D reconstructions: poor light conditions caused erroneous estimates of camera motion and 3D point distances

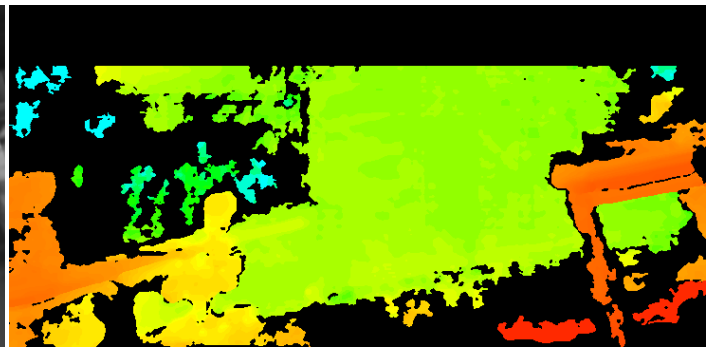
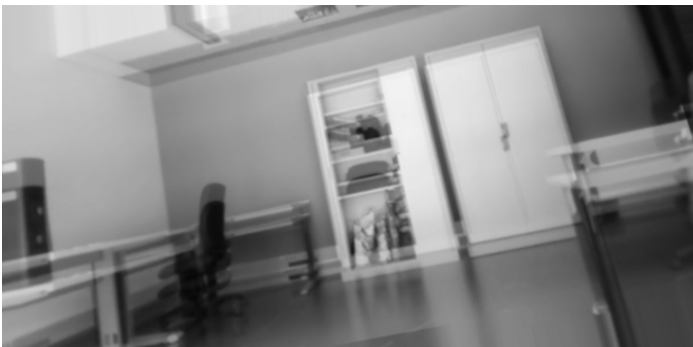


Figure 8. Dense 3D reconstruction results: The overlaid rectified images before and after the height change visualize the precision of the estimated camera motion (left). Therefore, any standard implementation for distance reconstruction, e. g. [13], may be used without modification (right).

periodically sent to them); the avionics sensor data that will be fed to the flight controller; finally telemetry data, sent to the control center. However, these flows may interact in subtle ways: for instance, the payload data may be used by the flight controller in order to do plausibility checks; attacks on these data may then result in further safety consequences.

Reference monitors will be introduced in order to regulate interactions between all components of the UAV in order to pervasively filter the authorized messages that they can exchange. We are also considering the possibility of virtualizing the execution of services in order to ensure a strong logical separation even within the same physical components. The introduction of embedded system boards featuring a large number of cores like the Parallela system (up to 64 cores) might prove interesting to support such a segmentation.

D. Real-time constraints

From a software point of view, the safety of the UAV relies on many usual software engineering criteria, including the satisfaction of real-time constraints, typically hard deadlines. Handling such constraints is particularly important in the flight control system where missing a deadline may lead to losing the UAV.

Security may as well impact them, for two reasons: first, attacks on the system could lead safety-critical functions to unpredicted reactions. For instance, a denial of service attack over the main bus of the UAV might exagerately delay the

orders sent by the control software to the actuators (i.e., engines). Second, the security mechanisms themselves may increase the system load, leading it to miss a deadline. For example, the encryption/decryption of a flight maneuver order could take too much time and delay the execution of a real-time task. It is thus important to assess the impact of security mechanisms over the safety-related functions. Similar issues have been addressed in other safety-critical systems, e.g., automotive systems [15].

VII. RELATED WORK

UAVs are now more or less ready for a growing number of civilian application areas, like personal daily assistance, agriculture, industry - including the building construction industry. The tasks assigned to the UAVs by the People's Republic of China (PRC) are one example, among others, of the importance taken by this technology [16], [17]. The MIT also recently featured the use of UAVs for agriculture as one of the 10 breakthrough technologies for 2014 [18].

The European Union is also taking measures for the progressive integration of Remotely Piloted Aircraft Systems (RPAS)⁴ in civil area by 2016 airspace [19]. Thus, the RPAS technology should soon lead to the development of a wide range of services, especially if the latter are associated with other technologies, such as precise positioning using the

⁴This acronym is used by the European Agency, and notably the Defense European Agency

Galileo positioning system, or used to support other technologies such as telecommunications in disasters.

The diversity of the tasks to be allocated to RPAS will also lead to search for different configurations with regards to the embedded payload. To give just one example, the GIX RPAS carries a radar operating at the dual frequency of 14 MHz and 35 MHz with respective bands of 1 MHz and 4 MHz in order to explore the ice cover at the South Pole [20]. It is clear that the performance required by such applications will lead to the design of specific and complex machines.

VIII. CONCLUSION AND FUTURE WORK

The design of a humanitarian UAV intended for intervention in post-disaster conditions is an important challenge [21]. Among all the high tech objects in our modern environment, UAVs have an impressively high potential to support post-disaster assistance and to extend the capabilities of rescue teams even if some difficulties must be tackled. The ever-increasing flight capabilities of lightweight UAVs coupled with the use of non-conventional sensors such as LIDARs and IR cameras will strongly increase the response capabilities of the operational rescue teams with respect to victim detection, terrain mapping, damage estimation, etc.

We sketched a new architecture in order to release the full potential of modern lightweight UAVs. We are currently designing such an architecture, mixing hardware and software along three layers. It revolves around an autonomy layer that supports and manages the achievement of mission objectives. UAVs will be successfully deployed in humanitarian missions only if their manipulation does not require special skills and does not hamper rescue teams in their normal tasks. This sine qua non condition explains the rationale of our focus on autonomous flight and mission management. For instance, UAVs should be able to manage their energy depending on the situation (mission duration) while ensuring the correct operation of control and command systems (decisional autonomy with regards to mission objectives). Flight safety has to be handled by reflex reactions developed in an emergency handling layer. Those mechanisms must be protected from all accidental or malicious interferences. Another architecture layer supports a flexible mission planning. This layer enables the real-time update of mission objectives. This update requires a secured communication protocol between a ground control station and the UAV. Safety and security properties must be introduced since the design phase. We will model and validate them with tools, in particular with TTool [22], a free open-source toolkit developed by Telecom ParisTech.

We also anticipate that the use of UAVs in a humanitarian context may bring up further sociological and societal issues. Further investigations will thus be needed to design appropriate man-machine interfaces in order to assist victims in critical conditions.

REFERENCES

[1] D. Guha-Sapir, P. Hoyois, and R. Below, "Annual Disaster Statistical Review 2012: The Number and Trends," in *CRED*, Brussels, Belgium, 2013.

[2] R. Chatterjee, B. Fruneau, J. Rudant, P. Roy, P. Frison, R. Lakhera, V. Dadhwal, and R. Saha, "Subsidence of Kolkata (Calcutta) City, India during the 1990s as observed from space by Differential Synthetic Aperture Radar Interferometry (D-InSAR) technique," *Remote Sensing of Environment*, vol. 102, no. 1-2, pp. 176–185, 2006.

[3] T. Tanzi and P. Perrot, *Télécoms pour l'ingénierie du risque (in French)*, éditions hermès ed. Collection Technique et Scientifique des Télécoms, 2009.

[4] T. Tanzi and F. Lefeuvre, "Radio Sciences and Disaster Management," *C.R. Physique*, vol. 11, pp. 114–224, 2010.

[5] P. Wilkinson and D. Cole, "The Role of the Radio Sciences in the Disaster Management," *Radio Science Bulletin*, vol. 3358, pp. 45–51, 2010.

[6] F. Lefeuvre and T. Tanzi, "International Union of Radio Science, International Council for Science (ICSU), Joint Board of Geospatial Information Societies (jBGIS)," in *United Nations office for outer Space Affairs (OOSA)*, 2013.

[7] T. Tanzi and F. Lefeuvre, "The Contribution of Radio Sciences to Disaster Management," in *International Symposium on Geo-information for disaster management (Gi4DM 2011)*, Antalya, Turkey, 2011.

[8] E. Ackerman, "Drone Adventures Uses UAVs to Help Make the World a Better Place," *IEEE Spectrum*, May 2013.

[9] Telecom ParisTech and EURECOM, "Drone4u project," <http://drone4u.telecom-paristech.fr>, 2014.

[10] B. Ranft, J.-L. Dugelay, and L. Apvrille, "3D Perception for Autonomous Navigation of a Low-Cost MAV using Minimal Landmarks," in *International Micro Air Vehicle Conference and Flight Competition (IMAV'2013)*, Toulouse, France, Sept 2013.

[11] L. Apvrille, J.-L. Dugelay, and B. Ranft, "Indoor Autonomous Navigation of Low-Cost MAVs Using Landmarks and 3D Perception," in *OCOSS 2013*, Nice, France, Oct. 2013.

[12] L. Apvrille, "Autonomous Navigation of Micro Drones," [youtube.com/watch?v=tamYpmGvzRw](https://www.youtube.com/watch?v=tamYpmGvzRw), 2013.

[13] H. Hirschmüller, "Stereo Processing by Semiglobal Matching and Mutual Information," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 30, no. 2, pp. 328–341, 2008.

[14] A. Dantcheva, J.-L. Dugelay, and P. Elia, "Person Recognition Using a Bag of Facial Soft Biometrics (BoFSB)," in *Multimedia Signal Processing (MMSp), 2010 IEEE International Workshop on*. IEEE, 2010, pp. 511–516.

[15] H. Schweppe, Y. Roudier, B. Weyl, L. Apvrille, and D. Scheuermann, "C2X Communication: Securing the Last Meter," in *The 4th IEEE International Symposium on Wireless Vehicular Communications: WIVEC2011*, San Francisco, USA, Sep. 2011.

[16] X. alfonsi, "Beijing Defines the Missions and Technological Innovations of his Current and Future UAVs (in French)," *Lettre confidentielles Asie 21 - Futuribles*, vol. 71, 2014.

[17] —, "Chine: quand la sinistraton des RPAS et du soft power prétend légitimer la vision régionale de Pékin en mer de Chine du Sud (in French)," *Lettre confidentielles Asie 21 - Futuribles*, vol. 71, 2014.

[18] C. Anderson, "Agricultural Drones: Relatively Cheap Drones with Advanced Sensors and Imaging Capabilities are Giving Farmers new Ways to Increase Yields and Reduce Crop Damage," *MIT Technology Review*, <http://www.technologyreview.com/featuredstory/526491/agricultural-drones/>, 2014.

[19] E. commission, "A New Era for Aviation Opening the Aviation Market to the Civil Use of Remotely Piloted Aircraft Systems in a Safe and Sustainable Manner," in *Communication De La Commission Au Parlement Européen et Au Conseil. COM(2014)*, Brussels, Belgium, 2014.

[20] C. L. et al., "UAS-Based Radar Sounding of the Pole Ice Sheets," *IEEE GRS Magazine*, March 2014.

[21] P. Marks, "Smart Software Uses Drones to Plot Disaster Relief," *NewScientist*, Nov. 2013.

[22] L. Apvrille, "TTool, an open-source toolkit for the modeling and verification of embedded systems," in <http://ttool.telecom-paristech.fr/>.