A Concept for Fast Indoor Mapping and Positioning in Post-Disaster Scenarios

Eduard Angelats and José A. Navarro
Centre Tecnològic de Telecomunicacions de Catalunya (CTTC/CERCA), Av. Carl Friedrich Gauss, 7. Building B4, 08860 Castelldefels, Spain

Keywords: RPAS Photogrammetry, Rapid Indoor Mapping, Indoor Positioning, 3d Modelling, Emergency Response, Orientation, RGB-D Camera.

Abstract: This work presents an early concept for a low-cost, lightweight fast mapping and positioning system suitable for civil protection and emergency teams working in post-disaster scenarios. Such a concept envisages continuous, seamless tracking in both indoor and outdoor environments; this would be possible because of the low geometric requirements set by emergency teams: knowing what is the floor and room where they are located is enough. The authors believe that current technologies (both hardware and software) are powerful enough to build such system; such an opinion is backed by an assessment of several currently available sensors (IMUs, RGB-D cameras, GNSS receivers), embedded processors and mapping and positioning algorithms as well as a feasibility study taking into account the several factors playing a role in the problem.

1 INTRODUCTION

The ultimate goal of the concept presented in this paper is to increase the safety of civil protection and emergency (CPE) teams working in post-disaster (either natural or man-made) scenarios, as earthquakes or fires. The members of these teams are constantly exposed to situations that may put their lives at (even death) risk. Such risk is significantly increased due to the lack of knowledge of the environment they work in - typically, confined spaces as damaged buildings.

Increasing such knowledge should have a direct impact on their security. Here, "knowledge" refers to information about the places (either outdoors or indoors) where these teams work. There exist, indeed, solutions to first map an area and then track people in booth indoor and outdoor enviroments. In the case of outdoors, there are nowadays many companies operating Remotely Piloted Aircraft Systems (RPAS) producing high quality cartography very quickly. Note, for example, that even the Copernicus Emergency Management Service (CEMS) offers a fast mapping service for emergencies using either Sentinel imagery or RPAS with a response time of about 48 hours – (CEMS, 2015); locating someone oudoors is also routinely performed: common solutions rely on Global Navigation Satellite Systems (GNSS) receivers or an hybridization of these with Inertial Measuring Unit (IMU) sensors. There also exist solutions for positioning in confined places, but these rely on pre-deployed infrastructure (as WiFi emitters/beacons or cameras, among others) that will not be available when working in post-disaster scenarios since these may be located anywhere. Solutions for indoor mapping based usually on Light Detection and Ranging (LiDAR) sensors carried either by humans or even by terrestrial robots exist (Kruijff-Korbayová, I. 2016), but these are not always suitable to operate in post-disaster scenarios; walls may have collapsed, debris or holes may impede their normal operation and, in the case of human carriers, operating in such situations is, doubtlessly, dangerous.

Thus, it is possible to say that, in practice, a suitable solution to track seamlessly the position of a CPE team when moving from outdoors to indoors - or viceversa - does not exist. As stated above, it is true that solutions in general do exist, but their dependance on some infrastructures make these unsuitable for emergency and disaster management. On the other side, it is the authors' belief that using the current technologies and algorithms it is possible to develop a system able to solve precisely this problem for the specific case of CPE teams.

Angelats, E. and Navarro, J.
A Concept for Fast Indoor Mapping and Positioning in Post-Disaster Scenarios.
DOI: 10.5220/0006780102740281
In *Proceedings of the 4th International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2018)*, pages 274-281
ISBN: 978-989-758-294-3

To focus the discussion aftewards, it is worth to note that outdoor mapping and positioning is nothing new nowadays. High levels of accuracy and precision far exceeding the requirements of CPE teams are achieved routinely. Therefore, and even though this paper presents a seamless solution for mapping and positioning in both indoor and outdoor environments, the outdoors case will not be discussed here from the mapping standpoint. Regarding positioning, the problem is solved too, but here a concept for a positioning device able to switch between outdoors and indoors conditions will be presented.

Such concept targets at a solution to overcome the difficulties stated above, relying on (1) a low-cost, lightweight, unobtrusive, portable device (2) to be carried as a payload by a special RPAS to map indoor environments and (3) to be carried afterwards by CPE members when inspecting the buildings. Note the double role played by the aforementioned device: mapper and tracker.

The sensors used to build such a device would be Red, Green, Blue and Depth (RGB-D) cameras, IMU sensors and GNSS receivers. Data fusion algorithms would be the heart of the system. These would combine raw observations coming from the IMU and the visual odometry solution estimated from RGB-D cameras' imagery to provide indoor positioning. The addition of a GNSS receiver immedately enables such device for outdoor environments. All these components (both hardware and software) should be mounted on a light, battery powered System-On-Chip (SOC) computer. Depending on the purpose (mapping or positioning), a different algorithm would be used.

Concerning the RPAS, not all of them would be appropriate for the task of mapping the interior of damaged buildings. Fixed-wing ones should be immediately discarded for obvious reasons. But even multi-copters may be severely damaged in case of crash against a wall. There exist, however, RPAS designed especifically to resist blows and crashes. These have been successfuly used for other purposes where flying in confined spaces was a must. See, for instance (Flyability, 2017).

This paper will try to show that it is already possible to build a low-cost fast 3D mapping and positioning system targeted at the specific needs of CPE teams using technology and algorithms already available. One of the factors making this possible is the low geometric (accuracy and precision) set by the regular operation of CPE personnel; basically, their members want to be sure about the floor and room they are in. This would translate to accuracies around 1-2 metres and precisions between 30-50 cm. To do it, sensors and algorithms will be presented and assessed together with the drawbacks derived from the specific work conditions usually present in the target scenarios - as suboptimal lightning, or presence of dust, usually found indoors in many kinds of natural or man-made disasters. The architecture of the mapping and positioning system will also be discussed.

2 THE STATE OF THE ART

2.1 Latest Trends in RPAS Mapping

According to (Gomez and Purdie, 2016; Colomina and Molina, 2014; Nex and Remondino, 2014), the number of publications referring to RPAS as a mapping tool has increased exponentially, reflecting the rapid spread of this technology. Such tendency played an important role in the significant reduction of price undergone by this equipment. Additionally, (Colomina and Molina, 2014) state that the improvement of automation software together with the decrease of price of processors and positioning and remote sensing sensors are responsible of the broad use of RPAS in the mapping arena. RPAS have become a suitable tool for mapping, because of their ability to carry a variety of mapping and positioning payloads, as cameras, LiDAR, IMUs or GNSS receivers (Giordan, 2017), so they may be used to support systems targeted at emergency management or hazard assessment. This may be done at local or even regional scales (Giordan, 2017), which depends on the kind of RPAS used, that is, fixed-wing or multi-copter ones (Gomez and Purdie, 2016; Boccardo, 2015). Last, but not least, one of the advantages of using and RPAS as a mapping platform is that these may be deployed very quickly. This means that RPAS are very suitable for mapping land features and, especially, their evolution over time or after sudden, violent transformations as flooding or volcanic eruptions. A non-exhaustive review of RPAS mapping for in the context of natural disasters may be found in (Gomez and Purdie, 2016).

Mapping emergency scenarios with the help of RPAS is usual when producing outdoors cartography. This technique is appreciated and valued by CPE and Search & Rescue (SAR) teams (Boccardo, 2015; Kruijff-Korbayová, 2016; Dominici, 2017; Scaramuzza, 2014). On the contrary, RPAS are almost unknown when working in indoor environments. Some research projects are the exception to the previous statement; (Kruijff, 2012; Kruijff-Korbayová, 2016), in the context of the projects NIfTi and TRADR, describe the use of aerial, RGB imagery to assess the damages suffered by buildings during the earthquakes that took place in Emilia-Romagna (2012) and Umbria (2016). 3D models were built in post-processing mode to perform the task. Leaving the area of emergency management, other mapping research projects exist. One of these is the work of (Mur-Artal and Tardós, 2017) where a variant of the Simultaneous Localization and Mapping technique (SLAM) called ORB-SLAM is presented.

With regard to algorithms and tools, a robust, widely used technique to produce 3D models using imagery obtained from Commercial Off-The-Shelf (COTS) cameras mounted on RPAS is the so-called Structure-from-Motion (SfM) approach (Nex and Remondino, 2014). One of the advantage of using the SfM approach is lower costs, especially when compared to those incurred when using an RPAS and a LiDAR sensor. Another advantage is the availability of a variety of highly automated tools such as Micmac (Pinte, 2017), Agisoft (Agisoft, 2017) or Pix4D (Pix4D, 2017). (Remondino, 2017) shows that using GPU-enabled, modern processors the time to collect and process data is noticeably reduced, thus leading to processing times in the range of a few hours, which fully aligns with the goal of quickly producing quality cartography when emergency management is the business.

LiDAR measurements may be combined with the positions or the trajectory to derive, in real-time either 3D models or Digital Surface Models (DSM). The geometric quality of the overlapping point cloud strips is directly influenced by the errors that may be present in the positions in the trajectory. To improve the quality of both the absolute and relative orientations and, consequently, that of the point clouds registration, a post-processing step is proposed in (Glira, 2016)

2.2 The State of the Art in Positioning and Mapping

In spite of being a tool widely used lately by most of the applications needing precise and robust positioning, the well-known GNSS have some drawbacks, such as the need of good environment conditions, as clear lines of sight; confined spaces or deep canyons (either natural or urban) are the typical environments where GNSS receivers are not the best technology for achieving precise positioning results. As already mentioned in section 1 and in the specific case of indoor environments, this limitation is usually overcome (Dardari, 2015) by means of the ad-hoc deployment of different kinds of emitters (as Wi-Fi, ultra-wideband or even visual beacons) that are complemented with the corresponding receiver, which, aided by the appropriate algorithms is able to estimate a solution. The emitters play the role of landmarks - also known as anchor nodes - since these have been deployed in known positions. This is not, however, the only approach used indoors. (Leutenegger, 2013; Veth, 2011) describe the use of combined IMU data and other sensors (as monocular, stereo or RGB-D cameras).

When using imaging sensors, it is possible to compute their orientation parameters by measuring tie-points in consecutive images that are conveniently overlapped. The extraction, description and matching of these tie-points have been the subject of quite a number of research works proposing several algorithms performing the aforementioned tasks in a robust way. Some of these (Lowe, 1999; Leutenegger, 2011) are, ideally, invariant to changes in illuminations conditions, orientation and scale. RANdom SAmple Consensus (RANSAC) procedures are usually combined with these algorithms in order to detect and remove outliers; this is done (Hartley and Schaffalitzky, 2004; Nister, 2003) using only image observations by means of position and attitude estimation. (Veth, 2011; Taylor, 2011) combine, instead, inertial data and derived trajectories to predict the appearance of already detected features in new images.

Removing outliers, it is possible to rebuild the trajectory by means of the concatenation of the estimated relative positions and orientations using k inliers from overlapping images. (Hartley, 2000; Scaramuzza, 2011; Forster, 2017) review several methods to estimate the navigation states using images with or without extra object observations. The robotics and computer vision communities refer to these approaches as SfM or visual odometry. These are called SLAM when drifts are reduced by means of reference maps or loop closures are detected. Another line of though (Taylor, 2011), present two strategies, both using an Unscented Kalman Filter and an IMU as the main positioning sensor; its drift is controlled by means of visual information. The first approach use image coordinates to set geometric constraints while the second estimates the navigation states at the same time than object coordinates.

3 THE CONCEPT

3.1 User Requirement and Scenarios

The concept for the system presented in this paper is oriented at helping the CPE teams to manage and assess post-disaster situations, especially in those cases where the damages inflicted to buildings is severe enough as to put the lives of the personnel having to intervene at risk of losing their lives. Not all the disaster scenarios are targets for this concept, but at least the following are: volcanic eruptions, landslides, earthquakes, fires, flooding, severe storms. In all cases, the system would be used once the emergency is over.

The proposed system (concept) would not be an independent one; it would complement the technologies and procedures that already exist, thus improving - or trying to improve - the management of emergencies, including the plans devised to handle these. From the temporal standpoint, such a system would be used during the intervention phase, that is, once the emergency itself (fire, earthquake or any other of the aforementioned situations) has finished. The idea, is to increase the safety of the members of the CPE teams, as well as to improve the resources available to the coordination personnel thanks to an assessment of the damages suffered by the buildings where these people have to work (for instance, being able to tell where the risk of collapsing walls is greater). This is an indirect way to say that the goal is reduce the risk these teams are exposed to, risks that sometimes take its toll on human lives. An extra benefit obtained from such a system would be the ability to help in building rehabilitation (thanks to the 3D models obtained during the intervention phase).

The system should be able to map the disaster area in only a few hours, both outdoors and indoors. Outdoors quality RPAS mapping is a service offered by many companies as a regular product. Among these, the Copernicus Emergency Management Service; therefore, it will not be discussed here.

But when talking about indoors and emergency management specifically, neither the positioning nor the mapping issues are well solved. In fact, many problems may affect the ability to create indoor maps in these environments. The authors, aware of these difficulties, restrict the scope of applicability of their work only to those cases in which the lightning and texture conditions are suitable for the kind of sensors integrating the system - namely, RGB-D cameras.

Thus, when possible, the system would produce 3D models of the damaged buildings, so the CPE teams know what they should expect when entering there. 2D floorplans are another possible output. An interesting discussion arising here is the quality level needed to produce these models; unlike other applications that rely on strict accuracy and precision requirements, emergency teams typically need just to be aware of their surroundings - that is, whether a dangerous wall that could collapse is around, if a staircase leading up or down is available or if the floor they should step on still exists, for instance - and what is the room and floor they are in. Such relaxed requirements make possible the concept to map and afterwards track personnel indoors described in this work. Nonetheless, the authors consider that minimum accuracy and precision requirements should be stated in order to assess the suitability of the system: 3 to 5 decimetres for precision and 1 to 2 meters for accuracy. Such requirements, moreover, allow for a representation of the buildings close enough to reality - so it is useful.

The availability of the 3D models and 2D floorplans opens the way to track the CPE teams and pinpoint their positions once they enter the buildings. This information (position) combined with the now available knowledge about the environment (holes, collapsed walls, availability of emergency exits, etc.) produces invaluable information for the member of both intervening and coordination teams. Again, some precision requirements should be set for the indoor positioning: below 10 meters. It is not possible, however, to assess accuracy since no reliable reference to compare to exist. Positions should be updated at least once per second (1 Hz) to effectively track the teams.

3.2 The Hardware

The system devised by the authors to implement both the mapping and tracking devices (or mapping payload and portable positioning device, respectively) will sport the same hardware components. A battery powered SOC board will be used to run the required algorithms (either positioning or mapping) and to integrate the required sensors. These will be and RGB-D camera plus an integrated GNSS / IMU module. This last module could be the ublox NEO-M8U (ublox, 2017) or a similar one. It has been chosen because its ability to work in two different modes; when a GNSS signal is available, it delivers a position with a frequency of 2 Hz (twice the required frequency). This would be the typical outdoor scenario, where GNSS is, normally, not a problem. But when moving indoors, this module switches to the untethered dead reckoning mode and delivers linear accelerations and angular velocities instead of position information - that is, the IMU data. The frequency is 20 Hz. This behaviour matches the operational mode that should be implemented in the mapping and tracking devices.

With regard to cameras, it is worth to note that the evolution of this technology has produced active RGB-D cameras able to take depth measurements in extreme lightning conditions - that is, 0 lux or no light at all. In such cases, the operating distance is drastically reduced, so, from the operational standpoint, data should be captured at much closer ranges. It is true that the accuracy and precision are also significantly worse; the key point here, however, is that using one of such active cameras instead of passive ones makes possible to operate the system when the illumination and texture requirements set in section 3.1 are not matched. Obviously, the complete absence of light (the 0-lux condition) may be too extreme for a pilot to be able to fly the RPAS; albeit, the idea is that even when the light is very poor, the system may be operated and results that may help to save lives, be obtained. Two cameras already available in the market would be good candidates for this system: the Intel© RealsenseTM (Keselman et al., 2017) and Microsoft Kinect 2 (Lachat et al., 2015). Unfortunately, the Kinect must be discarded because of excessive power consumption reasons (section 4 presents a feasibility analysis, and power consumption is one of the factors to take into account).

Finally, an unobtrusive SOC (also with low power requirements) would be desirable to complete (and integrate) the set of components making the system. Its task, to provide with the necessary computing resources - positioning version - and storage capacity (mapping version, sensor data must be saved). The word unobtrusive above means lightweight and small footprint in this context, since the positioning device must not be a nuisance to its wearers. Obviously, the low consumption requirements lead to longer operational times, thus reducing the need to replace batteries so often. From the computing power standpoint, a powerful GPU is a must, due to the image processing computations that must take place in real time. A possible candidate for the SOC is the NVIDIA Jetson TX2 (Franklin, 2017).

3.3 Operating the System

From the operational standpoint, using the system in indoor environments implies going through three main steps, namely data collection, map generation and actual intervention.

First of all, data must be collected using the mapping payload on board the RPAS. As already stated in section 3.2, the integrated GNSS + IMU module will provide GNSS-based data while operating outdoors, so the RPAS position and attitude will be computed relying on this information. The camera plays no role at this stage (since the goal of this procedure is to produce **indoor** cartography). It is important to collect this information since it will be used as (presumably good) initial approximations for the attitude and position of the RPAS when it enters the building and the GNSS signal disappears. As soon as this happens, the system will activate the RGB-D sensor and the GNSS + IMU module will start delivering linear accelerations and angular velocities. It should not be forgotten that the imagery and IMU data stored to later produce the 3D models (and 2D floorplans) must be correctly time-tagged. When leaving the building, the GNSS-based operations mode is reactivated, so, again, more precise position and attitude data will be available, helping to improve the final quality of the mapping process. The RPAS itself deserves a few words; usual RPAS are not suited to operate in confined spaces because of the high risk of crashing against the walls or any debris that may be present inside the building. Such crashes or blows may damage - and therefore, disable - the RPAS itself. To overcome such difficulties, multicopters adapted to fly in such circumstances exist. Flyability's (Flyability, 2017) is one example of RPAS used successfully in projects requiring flying indoors.

Once the drone exists the building, it is necessary to download the data and compute the 3D models and 2D floorplans. The usual software workflow and tools used for such task are described in section 3.4. The time needed to obtain these products will directly depend on the dimensions of the building(s) to process, although current software is pretty fast and able to deliver results in short times. However, it must be noted that RGB-D cameras may deliver a coarse point cloud immediately. Since it has not been processed, the accuracy and precision of such data will never be as good as that of the products obtained after a post-processing step; nonetheless, and in very critical situations, the availability of a first point cloud in so short a time may prove vital for the CPE teams, being possible for them to enter a building with first-hand knowledge about it. When there are lives at a stake, coarse point clouds may make the difference.

Then, the CPE teams, carrying the portable positioning device, will proceed to enter the already mapped buildings. Their position will be computed in real-time by means of visual odometry plus IMU data.

Ideally, this position should be sent to the control team outside the building so they can track the position of the personnel. This, obviously, implies the use of some kind of communications that will not be described in this paper. Note that, depending on the conditions indoors (dust, no lightning, smoke, etc.) the portable device might be unable to compute positions. Even in this case, the 3D models and 2D floor maps in the hands of the control team are invaluable tools: these may be used to guide the teams inside the building using classic communication channels - for example, telling them where to find holes, collapsed ones, debris, or any other obstacles that might interfere in their task.

3.4 About the Software

Although the portable positioning device and the mapping payload share the same SOC and sensors, the software used to manage it will be different depending on how it is used.

When used as a **portable positioning device**, two situations may be told apart: indoors and outdoors positioning. The last of these two cases is well known and usually solved by means of GNSS receivers; in the concept presented here, IMU data will be used to enhance position and attitude data. The well-known extended Kalman filter - or sequential least squares algorithm - is the engine to use to do so (Parés and Colomina, 2015). Data will be referred to a global reference frame. But as soon as the emergency team enters a building, thus being indoors, the device will change its mode of operation, thus using a different algorithm. Since the GNSS signal will not be available, the RGB-D cameras plus the IMU raw data will be used instead. Again, an extended Kalman filter will be used. The IMUs will play the main role in the prediction step, producing orientation and position data in a global reference frame. On the contrary, and during the filter step, the orientation and position data derived from the processing of the RGB-D images (visual odometry) will be responsible for updating the predicted ones, in order to control the drift introduced by the inertial sensors. In this step, data is referred to a local reference frame, but it is possible to compute their equivalent in the global one using the level arm and boresight matrices. Finally, a common temporal reference frame is necessary to correctly deal with data coming from these two sources - the internal clock of the SOC will be enough for the purposes of this concept.

When the device is used as a **mapping payload**, it is targeted at the production of the 3D models and 2D floorplans. Once that the data (GNSS -outdoors-, IMU - indoors + outdoors - and RGB-D images - indoors) have been downloaded, three steps are necessary to do it.

In first place, it is necessary to estimate the (coarse) initial approximations of the positions and attitude values related to the imagery. The algorithm is the same used by the device when working as a portable positioning device (see above). Secondly, a block adjustment will take care of refining these initial approximations so much better values are obtained. Depending on the community, this step is known as SfM or "Integrated Sensor Orientation". This task may be done using any of the software packages available nowadays, as Pix4D (Pix4D, 2017), AgiSoft (AgiSoft, 2017) or Micmac (Pinte, 2017). Finally, the depth data obtained from the RGB-D camera together with the position and orientation data just refined will be used to produce a dense point cloud. A popular software library able to do this is PCL (PCL, 2017).

4 FEASIBILITY

Going from a concept to an actual, working implementation safely, implies a feasibility analysis. Some factors that must be taking into account in such analysis have a direct impact on the hardware use to implement the positioning / mapping device.

Power consumption. Some RGB-cameras are pretty greedy regarding power. Obviously, higher power consumption implies less operating time and the unsuitability of the camera for the purposes of this work. This is the case of the Microsoft Kinect v2.

Extra hardware or software requirements. Some cameras, including again the Kinect v2, require extra hardware to work properly and to deliver the performance needed to fulfil the pursued goals (Chesa, 2017). Examples of these extra requirements are GPUs, OpenGL, or USB 3.0 ports.

SOC performance. Several authors have tested the suggested SOC, the NVIDIA Jetson TX2, showing that it is capable enough to produce the necessary output rate in terms of positions per second when using the algorithms and techniques described in this paper (Mur-Artal and Tardós, 2017; Forster, 2017).

Common temporal frame. The positioning / mapping device collects data originating in different sensors (the RGB-D camera and the GNSS + IMU module). The algorithms used to produce positions or maps out of these observations need to know the precise time when these observations were generated, and such time must be referred to a common temporal frame for all the sensors involved in the process.

Systems having to match high-quality geometric constraints normally use devoted hardware to provide the aforementioned temporal reference frame. In the case discussed here, the SOC's internal clock is enough, specially (although not necessarily) if the drifts and latencies existing in the system are properly characterized.

Pre-heating time, calibration and RGB-D data quality. An incorrect (or inexistent) geometric calibration or too short pre-heating times may produce systematic errors in the quality of the depth measurements that have direct implications in that of the derived point cloud (Chesa, 2017; Keselman, 2017; Lachat 2015). It is worth to note that the geometric requirements in the context of this application are so relaxed that the aforementioned problems are negligible in this case.

Environmental operating conditions. Visual odometry needs some minimum operating conditions to work, especially those regarding illumination and texture. The operating range as well as the quality of the depth measurements directly depend on them. The immediate consequence is that the quality of the positioning / mapping solution, relying on the extraction of features of the RGB-D imagery, is also affected. (Mur-Artal and Tardós, 2017; Forster, 2017) discuss how feasible is to operate in moderate illumination conditions. Note, also, that the when using active sensors (infrared emission) it is possible to work in near 0-lux lightning conditions, although the operating range is still shorter.

Mapping post-processing times. According to (Remondino, 2017), the photogrammetric software packages currently available are powerful enough as to deliver results in times short enough as to meet the requirements set by post-disaster, emergency scenarios. Furthermore, the limited autonomy of RPAS still reinforces the previous statement, since the amount of data to process will be relatively small, thanks to the capabilities of the aforementioned software packages and current computers.

RGB-D cameras' extra cost. RGB-D cameras are slightly more expensive than RGB ones but, according to (Mur-Artal and Tardós, 2017; Fang, 2015) the extra features these incorporate are worth of it. RGB-D cameras are still able to produce robust solutions in poor or changing illumination conditions. Finally, the point cloud these cameras provide may be improved (see previous point above) by means of post-processing techniques, delivering useable 3D models in very short times.

5 CONCLUSIONS

This work was motivated by the risk that CPE teams take whenever they enter damaged buildings in post-disaster scenarios. The main goal was to check whether a fast indoors mapping / positioning system, relying on no pre-deployed infrastructures, and delivering 3D models with a quality enough to fulfil the needs of that teams, could be feasible using currently available technologies and recent advances in algorithms.

A thorough state of the art has been presented, showing the most recent technology and algorithms; a concept, relying heavily on that information, has been detailed, explaining how such a system could be built and exploited. A feasibility analysis, highlighting the most relevant issues has also been included.

This paper presents just a concept and not an actual implementation of the system. Nonetheless, the performances, features, algorithms and procedures already explored and documented by many other researchers have convinced the authors that such a system is feasible nowadays. And that it is possible using low-cost equipment, which would facilitate its adoption by many civil protection agencies.

REFERENCES

Agisoft, 2017. *Agisoft Photoscan*. http://www.agisoft.com. Accessed: 30 November 2017.

Boccardo, P., F. Chiabrando, F. Dutto, F. Giulio Tonolo, and A. Lingua. 2015. *UAV Deployment Exercise for Mapping Purposes: Evaluation of Emergency Response Applications. Sensors 15: 15717–15737.*

CEMS, 2015. *Copernicus Emergency Management Service Mapping. Manual of Operational Procedures Guidelines for EC Services, Service Providers and Authorized Users. European Commission DG GROW, DG ECHO, DG JRC. Version 1.1 February 2015.*

Chesa, M., 2017. *Obstacle avoidance for an autonomous Rover. Bachelor degree thesis Technical University of Catalonia, 2017.*

Colomina, I., and P. Molina. 2014. *Unmanned aerial systems for photogrammetry and remote sensing: A review. ISPRS Journal of Photogrammetry and Remote Sensing 92: 79–97.*

Dardari, D., Closas, P., Djuric, P, 2015. *Indoor Tracking: Theory, Methods, and Technologies. IEEE Transactions on Vehicular Technology, 64(4), 2015,* 1263-1278.

Dominici, D., Alicandro, M., Massimi, V., 2017. *UAV photogrammetry in the post-earthquake scenario: case studies in L'Aquila. Geomatics, Natural Hazards and Risk* Vol. 8, Iss. 1, 2017.

Fang, Z.; Zhang, Y., 2015. *Experimental Evaluation of RGB-D Visual Odometry Methods. International Journal of Advanced Robotics Systems 2015*, 12, 1–16.

Flyability, 2017. *ELIOS - Inspect & explore indoor and confined spaces.* http://www.flyability.com/elios. Accessed: 30 November 2017.

Franklin, D., 2017. *NVIDIA Jetson TX2 delivers twice the intelligence to the edge.* https://devblogs.nvidia.com/parallelforall/jetson-tx2-delivers-twice-intelligence-edge. Accessed: 30 November 2017.

Forster, C., Zhang, Z., Gassner, M., Werlberger, M., Scaramuzza, D., 2017. *SVO: Semi-Direct Visual Odometry for Monocular and Multi-Camera Systems. IEEE Transactions on Robotics*, Vol. 33, Issue 2, pages 249-265, Apr. 2017.

Giordan, D., Manconi, A., Remondino, F. and Nex, F.C., 2017. *Use of unmanned aerial vehicles in monitoring application and management of natural hazards: open access. Geomatics, Natural Hazards and Risk, 8 (2017)*1 pp. 1-4.

Glira, P., Pfeifer, N., Mandlburger, G., 2016. *Rigorous Strip Adjustment of UAV-based Laserscanning Data Including Time-Dependent Correction of Trajectory Errors. Photogrammetric Engineering and Remote Sensing, 82 (2016)*, 12; 945 – 954.

Gomez, C., Purdie, H., 2016. *UAV- based Photogrammetry and Geocomputing for Hazards and Disaster Risk Monitoring – A Review. Geoenvironmental Disasters, 2016*, Volume 3, Number 1, Page 1.

Hartley, R. and Zisserman, A., 2000. *Multiple view geometry in computer vision. Cambridge University Press*, 2nd edition.

Hartley, R. and Schaffalitzky, F., 2004. *Minimization in geometric reconstruction problems. In: Proceedings of Computer Vision and Pattern Recognition conference, 2004.*

Keselman, L., Iselin Woodfill, J., Grunnet-Jepsen, A., Bhowmik, A., 2017. *Intel© RealSenseTM stereoscopic depth cameras. In: Proceedings of IEEE Conference on computer vision and pattern recognition workshops (CVPRW)*, 21-26 July 2017, Honolulu, HI (USA).

Kruijff, G.-J., Tretyakov, V., Linder, T., Pirri, F, Gianni, M., Papadakis, P., Pizzoli, M., Sinha, A., Pianese, E., Corrao, S., Priori, F., Febrini, S. and Angeletti, S., 2012. *Rescue robots at earthquake-hit Mirandola, Italy: A field report. In IEEE Intl. Symp. on Safety, Security, and Rescue Robotics (SSRR)*, 2012.

Kruijff-Korbayová, I. 2016. *The Use of Robots for Disaster Response". Presentation at CTIF Delegates Assembly & Symposium, Sep 8-9 2016 in Helsinki.*

Lachat, E., Macher, H., Landes, T., Grussenmeyer, P., 2015. *Assessment and calibration of a RGB-D Camera (Kinect v2 sensor) towards a potential use for close-range 3D modeling. Remote Sensing 7(10):13070-13097.*

Leutenegger, S., Chli, M., Siegwart, R., 2011. *BRISK: Binary Robust Invariant Scalable Keypoints. In: Proceedings of the IEEE International Conference on Computer Vision (ICCV), 2011.*

Leutenegger, S., Furgale, P.T., Rabaud, V., Chli, M., Konolige, K. and Siegwart, R., 2013. *Keyframe-Based Visual-Inertial SLAM using Nonlinear Optimization, In: Proceedings of Robotics: Science and Systems, 2013.*

Lowe, D., 1999. *Object recognition from local scale-invariant features. In: Proceedings of the International Conference on Computer Vision (ICCV), 2011.*

Mur-Artal R., and Tardós, J.D, 2017. *ORB-SLAM2: an Open-Source SLAM System for Monocular, Stereo and RGB-D Cameras. IEEE Transactions on Robotics*, vol. 33, no. 5, pp. 1255-1262, June 2017.

Nex, F.C., and Remondino, F., 2014. *UAV for 3D mapping applications: a review. Applied Geomatics, 6 (2014)1 pp. 1-15.*

Nister, D., 2003. *An efficient solution to the five-point relative pose problem. In CVPR03.*

Parés, M.E., Colomina, I., 2015. *On software Architecture Concepts for a Unified, Generic and Extensible Trajectory Determination System. In: Proceedings of the ION GNSS+, 08-12* September 2015, Tampa, Florida (USA).

PCL., 2017. *Point Cloud Library (PCL).* http://pointclouds.org/. Accessed: 7 February 2018.

Pinte, A., 2017. *Micmac, un logiciel pour la mise en correspondance automatique dans le contexte géographique.* http://logiciels.ign.fr/?Micmac. Accessed: 30 November 2017.

Pix4D, 2017. *Pix4D - Drone photogrammetric software for desktop + cloud + mobile.* https://pix4d.com. Accessed: 30 November 2017.

Remondino, F., Nocerino, E., Toschi, I., and Menna, F, 2017. *A Critical Review of Automated Photogrammetric processing of large datasets.* In: Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W5, 591-599, 2017.

Scaramuzza, D. and Fraundorfer, F., 2011. *Visual Odometry [Tutorial]*. IEEE Robot. Automat. Mag. 18(4): 80- 92.

Scaramuzza, D. et al., 2014. *Vision-Controlled Micro Flying Robots: From System Design to Autonomous Navigation and Mapping in GPS-Denied Environments.* IEEE Robotics & Automation Magazine, vol. 21, no. 3, pp. 26-40, Sept. 2014.

Taylor C.N, Veth M.J., Raquet J.F., Miller M.M, 2011. *Comparison of Two Image and Inertial Sensor Fusion Techniques for Navigation in Unmapped Environments.* IEEE Transactions on Aerospace and Electronic Systems, vol. 47, no. 2, pp. 946–958.

ublox, 2017. *NEO-M8U module.* https://www.u-blox.com/en/product/neo-m8u-module. Accessed: 30 November 2017.

Veth, M.J., 2011. *Navigation Using Images, A survey of Techniques.* Journal of Navigation 58(2), pp. 127–140.