GRAPHICAL TOOLS TO THE RESCUE. HIGH RESOLUTION AERIAL PHOTOGRAPHY FOR THE LOCATION OF MISSING PERSONS

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ABSTRACT:

Since the COVID-19 pandemic changed the rules of the game in many work environments, adaptation has been a key factor. Restrictions such as social distance or confinement made searches for missing persons more difficult. Although mobility limitations led to a decrease in the number of disappearances, they did not stop completely and search teams had to adapt to the new scenario that prevented, for example, the participation of volunteers. For these reasons, it was decided to implement a tool that had been in development for years, based on the Collaboration Agreement signed in 2015 between the Servicio de Prevención y Extinción de Incendios de la Diputación Provincial de Zaragoza (SPEI-DPZ) and the University of Zaragoza. The tool is called Virtual Cloud Search and Rescue (VC-SAR) and is still under development by the authors of this communication. The following is a basic description of the tool and how it was applied in a real case, in which a missing person was being searched for. The device used made it possible to obtain about 5000 images of 44.7 mega-pixels, covering an area of over 2000 hectares. Thanks to the searches carried out, more than 100 pieces of evidence were found over the course of four days, which could be collected for on-site investigation by the Navarra Fire Service. All this was possible thanks to the collaboration of 5 different fire departments, belonging to three provinces, making possible the participation of a total of 53 searchers from different locations.

Keywords: Graphical tools; Aerial images; Search and rescue; Drones.

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1.- INTRODUCTION

In a search for missing persons, all necessary safety measures must be taken to ensure that the participants are exposed to the minimum amount, with the safety of all those involved in the operation being the primary objective [1]. For that purpose, a variety of factors must be taken into account, as explained in the guide developed by the Arizona Search and Rescue Coordinators

Association [2]. In addition to factors such as terrain and weather conditions, those related to the COVID-19 pandemic had to be added. One of the measures implemented in workplaces, both indoors and outdoors, was social distance, considered a key factor in many countries [3]. To this social distance, drastic mobility reduction measures soon had to be added, as it was considered one of the main categories in terms of mitigating the risk of spreading the coronavirus [4].

Thus, in the searches for missing persons carried out since the early 2020s, the participation of volunteer searchers, who in many cases could be dozens or even hundreds, has had to be significantly limited or even completely absent [5, 6]. As described by Haghani et al. [7], in the safety-related research published shortly after the start of the pandemic, there was a sudden shift in many professional activities, from clinical care to education, drastically moving them closer to online environments.

In a scenario such as the one described, with notable limitations imposed by the pandemic, the application of advanced technologies was considered essential in search and rescue operations for missing persons. The use of unmanned aerial devices or drones is a clear example of how technology can help in this type of operations. In fact, these devices have proven to be useful in evaluating different types of disasters, such as floods [8–10], earthquakes [11–13] or volcanic eruptions [14].

In fact, the use of aerial photography cannot be considered new at all. For example, during the Second World War, the Photographic Reconnaissance Unit flew over European skies taking tens of millions of photographs trying to identify clues [15]. Drones have also been used in search operations for missing persons for years, such as locating a child in Minnesota [6], a climber over 5000 m on Alaska's Mount McKinley [2], or a mountaineer descending one of the Himalayan peaks [16].

In this chapter, it is explained how the use of high-resolution images, captured by experienced drone pilots, can be key to minimise the risks to be assumed during the search for a missing person, specifically in a small town in Navarra (Spain) [17, 18]. The review of the images, by previously trained professionals, complemented the on-site searches, helping to reduce risks and increase efficiency.

The method followed is described below, with special emphasis on the graphical tool used and going on to describe the results obtained.

2 METHOD

This section describes the method followed to carry out the search for the missing person [17, 18], taking as a reference the search management tool that is being developed by the authors of this communication.

2.1 Structure of the tool

The tool has a client-server structure, so that users can access it using any web browser, from virtually any device running any operating system that allows it. The tool was implemented in XAMP, programming the backend in PHP and the frontend in JavaScript.

Through the control panel, the system allows to manage the users who can access the different available tools, according to the assigned permissions. Users are grouped into three roles, depending on the work they are going to perform. These roles are:

- Search manager: Responsible for the search. The main tasks are: Registering the search, registering the sectors to be mapped, defining the structure of the lots of photographs to review (datasets). As soon as indications are communicated, the search manager is also in charge of reviewing and helping to make decisions about verifying them on the ground. Once the search is finished, this manager documents and provides the most relevant information to the Advanced Command Post or Puesto de Mando Avanzado (PMA).

- Pilot: In charge of programming the flights, piloting the drone and taking the photographs to map the sectors established by the PMA. At the end of each flight, pilots must upload the captured images to the system, indicating the sector to which they belong, as well as the data of the drone and the camera used.

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• Virtual searcher: With access the photographs taken, grouped in lots, to analyse them in search of clues. When clues are found, they are reported, so that they can be reviewed by the search manager.

2.2 Capture of images

The director of the search, from the PMA, decides the sectors to be mapped, based on the known planning data. These can be, among others, the last point of sight and the last known position, with the aim of establishing an initial planning point. The objective is to fly over and photograph the sectors that have a greater probability of success.

The Matrice 300 RTK is a high-capacity drone, with important specifications that make it especially suitable for search and rescue missions. Among others, we could stand out:

- Payload capacity: 2.7 kg (9 kg MTOW)
- Maximum flight autonomy: 55 minutes
- Protection index: IP45
- Resistance to winds of maximum 15 m/s
- Operating temperature from -20 to 40ºC

The captured images, such as Fig. 1, were taken by a Zenmuse P1 camera, with 35 mm lens. This device was on board of a Matrice 300 RTK drone and both products are manufactured by DJI [19].

Fig. 1. One of the high-resolution aerial images captured by the drone

The Zenmuse P1 is a full frame camera, with the following features:

- Sensor:
  - o Size (snapshot): 35.9 × 24 mm
  - o Effective pixels: 45 MP

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- Shutter:
  - o Type: mechanical
  - o Shutter speed: 1/2000 - 1 s
- Aperture range:
  - o f/2.8-f/16
- ISO range:
  - o 100-25600

2.3 Organization of the photographs

The pilot is responsible for uploading the images to the system at the end of each flight. Depending on the flight parameters and the camera used, in each take-off it is possible to take from 100 photos to more than 1000. Once the images are received, the tool reads the files, calculates and records the height of the flight, as well as dimensions and the geographical reference and orientation of the photos, among other data.

The search manager is in charge of defining the structure of the lots of photos to review. Each of these lots (also called datasets) will be assigned to a virtual searcher for their analysis.

When defining the lots, the number of photos (between 15 and 20) must be specified, as well as the priority (those with higher priority will be reviewed first) and the number of times they must be reviewed (two or even more, when the probability to find the lost person in that sector is considered high, according to previously studied parameters).

2.4 Analysis of the photographs

Users with the role of virtual searcher can access the system to analyse the photographs. After login, they open the first available lot, based on the priority that was stablished by the search manager.

Once an image has been analysed, the next one is automatically displayed, continuing this process until the assigned lot is completed. If necessary, it is possible to review previous images again.

In the application, the analysis window provides different graphical tools to facilitate the search work:

- Alphanumeric box with the relevant data of the search: contact with the PMA, data of the missing person, number of photos reviewed / pending, etc.
- Magnifying glass tool, which allows the virtual searcher to enlarge the display scale around the cursor to avoid having to change the scale of the window to observe the details.
- Measurement tool, to obtain a real idea of the size of the elements displayed.
- Tools to mark the clues, being possible to indicate the category of the clue found, as well as the urgency of its subsequent review by the search manager.

At the end of the analysis of each lot, the virtual searcher is asked to complete a very simple form, where he indicates, mainly, his level of fatigue, in addition to the technical characteristics of the device used for this analysis. The user must manually enter the monitor size. The form contains the details to calculate the size, by measuring its diagonal. The screen resolution is calculated automatically from the size of the window used for the search. A text box is also made available to the searcher being possible to add observations that may be interesting.

The search manager can review the results of this query to adjust the number of photos in each lot, to improve the efficiency of the analysis process.

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2.5 Management of reported signs

The clues that are communicated by each searcher are displayed, in real time, on the control panel. Those clues are organized by their level of urgency, category and date and time in which they were uploaded.

The search manager reviews each of the clues with the available graphical tools, similar to those used by virtual searchers. After this, the search manager decides the urgency of each clue and can change its status according to the needs. The states through which the indications can pass are the following:

- Informed: The virtual searcher has communicated a clue during the analysis.
- Pending verification: The search manager has reviewed the clue and considers that it needs to be verified in the field (on-site).
- In the verification process: The search manager has generated a KML file, which includes the clues previously marked as pending verification, and has sent it to the personnel on-site for direct verification.
- Verified: On-site staff has accessed the georeferenced position in the index and verified it, indicating the result to the search manager.
- Discarded: Once the clue on the photograph has been reviewed or once the clue has been verified on the ground, it can be discarded if it is not useful for the search.

2.6 Final report of the search

The search manager can generate a report on the status of the search. It includes the most significant data regarding take-offs, photographs, reviews and searchers. These data allow the search manager to resolve the different problems that may appear.

The report that is generated, after the search is finished, is made available to the decision makers, for their knowledge. On the other hand, it also allows the tool development team to analyse the recorded data with the intention of implementing improvements.

2.7 Training of virtual searchers

In order to use this graphical tool, it was necessary to follow a continuous training plan for the firefighting services involved. First, specific training courses were given to each of the roles performed in the system: search manager, pilots and virtual searchers. Periodically, generally once a month, the simulation of a search process is done, in which all the roles take part with the available devices.

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Fig. 2. Training session for virtual searchers

3 RESULTS

3.1 Defined sectors

Following the PMA guidelines, 4 sectors were mapped. The first one was registered in the system on 11/02/2022, at 18:38, and the last one on 12/02/2022, at 22:10. The combined area of the 4 sectors covered an area of 223 hectares.

3.2 Take-offs

The first assigned mission, corresponding to a specific area of the Onsella river, in the province of Zaragoza, covered a total area of 67 hectares. For completing it, three take-offs were required. A flight was configured with a significant percentage of frontal and lateral overlap, with an average height above the ground of 100 m above ground level (AGL). It was completed in 68 minutes and 889 images were obtained, with a ground sampling distance (GSD) of 1.22 cm/px.

The second assigned mission, corresponding to a total area of 139 hectares, divided in two zones, was completed with seven take-offs. In the first area of this second operation, 5 take-offs were carried out, with an average height of 80 m AGL. It was finished in 118 minutes and 2240 images were obtained, with a GSD of 0.98 cm/px. For the second zone, two take-offs were required, with an average height of 70 m AGL. It finished in 62 minutes and 1554 images were obtained, with a GSD of 0.85 cm/px.

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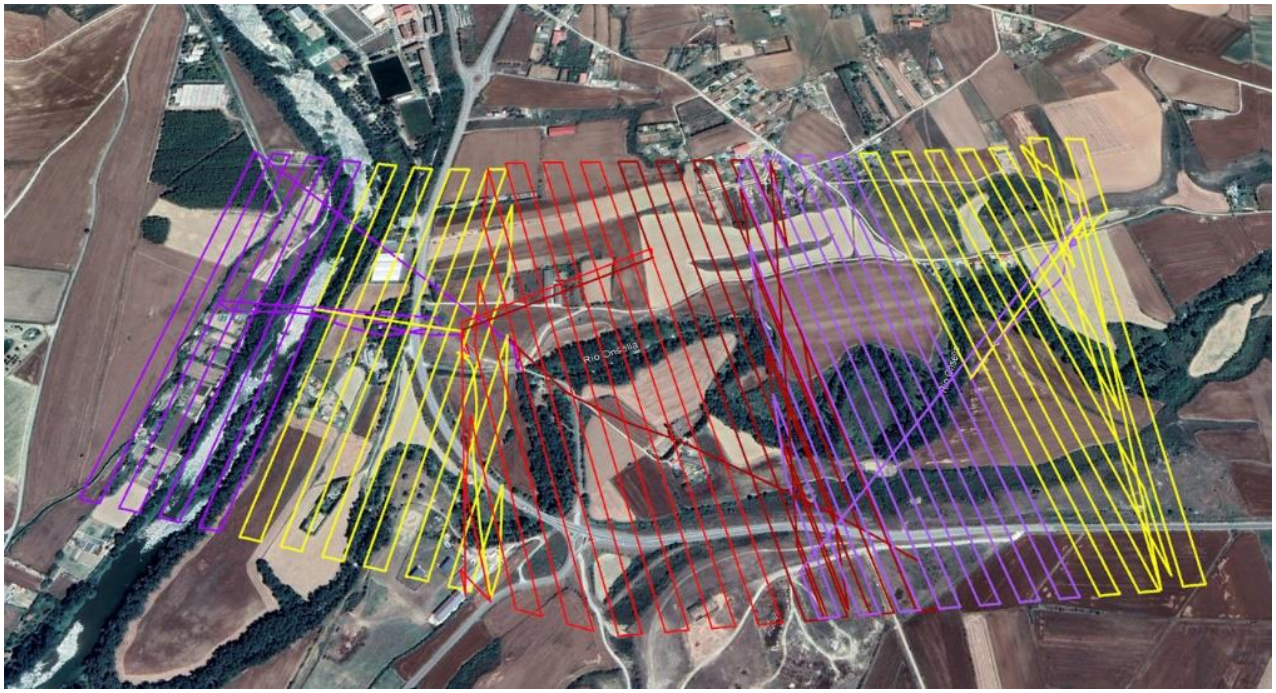

Fig. 3. Complete path of the second assigned mission

The photographs of the first take-off were uploaded on 11/02/2022 at 19:00 to the server and those of the last one on 13/02/2022 at 10:08.

The flight time of the drone was 6 hours and 42 minutes, covering a linear distance of 80 km.

The pilots uploaded a total of 4932 valid photos to the server, occupying a total of 91.3 Gigabytes on the server.

The total area covered by each of the photographs is 2141 hectares.

3.3 Organization of the photographs

The photographs taken were organized in 461 lots, with a total of 4932 files. Lots were divided in groups of 15 to 29 photographs, with a mean of 18.2 images per lot (SD: 2.7).

327 lots (6135 photographs, 73%) were assigned the highest priority, while 134 lots (2264 photos, 27%) were assigned the lowest priority.

3.4 Analysis of the searches

466 lots were reviewed (5 more than the total number of lots, as explained in section 4.2). The first analysis began on 11/02/2022 at 19:12, twelve minutes after uploading the photos of the first take-off. The last analysis started four days later, on 14/02/2022 at 14:08.

In total, the virtual searchers spent 226 hours and 52 minutes analysing the 8399 photos (part of the 4932 files were reviewed several times), with a total area of 4282 hectares.

3.5 Analysis of the searchers

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In total, 53 different searchers participated, reviewing the 466 lots of photographs. On average, each searcher analysed an average of 8.8 lots (SD: 10.3), with a maximum of 44 and a minimum of 1. Grouping them, 22 searchers analysed less than 4 lots, 21 analysed between 4 and 13 lots and 10 analysed more than 13 lots.

Regarding the time invested in the search, each one dedicated an average of 4 hours and 17 minutes (SD: 4:22) with a maximum of 19 h 12 minutes and a minimum of 3 minutes.

On average, each searcher spent 37.5 minutes (SD: 14.7) reviewing each lot of photographs, with a maximum of 87 minutes and a minimum of 8. Grouping by the searching time spent on each lot, 9 searchers required less than 20 minutes per lot, 32 analysts took between 20 and 50 minutes per lot, and 12 searchers needed more than 50 minutes to review each lot.

3.6 Analysis according to the service to which the searchers belong

Another important aspect to consider is the searchers' membership in the different fire prevention services. The participation data by fire service is summarized below (Table 1).

Searchers	*Fire service*
4 (7.5%)	Ayuntamiento de Huesca
4 (7.5%)	Ayuntamiento de Zaragoza
2 (3.8%)	Diputación de Huesca
11 (20.8%)	Diputación de Teruel
31 (58.5%)	Diputación de Zaragoza
1 (1.9%)	Gobierno de Aragón-Servicio SPC
Analysed lots	*Fire service*
29 (6.2%)	Ayuntamiento de Huesca
18 (3.9%)	Ayuntamiento de Zaragoza
46 (9.9%)	Diputación de Huesca
130 (27.9%)	Diputación de Teruel
239 (51.3%)	Diputación de Zaragoza
4 (0.9%)	Gobierno de Aragón-Servicio SPC
Total searchers:	*53*
Total lots:	*466*

Table 1. Participation data by Fire Service.

3.7 Devices used in the analysis by searchers

The average size of the monitor used for the reviewing process by the searchers was 19.9 inches (SD: 6.7), with a maximum of 42 and a minimum of 13. It must be considered that in 71 (15.2 %) of the 466 searches, the dimensions of the screens were not indicated by the searchers.

The average resolution is close to the standard 1920 x 1080 (SD: 606 x 333), with a maximum of 3840 x 2160 and a minimum of 1024 x 768.

3.8 Level of tiredness

The average level of tiredness per search was 2.2 (SD: 0.9), measured with a Likert scale, with a maximum of 5 (extreme tiredness) and a minimum of 1 (no tiredness). In this case, in 61 (13.1%) of the 466 searches, the level of fatigue was not indicated.

3.9 Reported signs

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In total, 110 clues were reported, of which 19 (17.3%) were repeated. The level of urgency reported was normal (in 66.4% of the indications) or low (in the remaining 33.6%).

The reported signs, grouped by category, were as follows:

Number of clues	*Category*
23 (20.9%)	Object
21 (19.1%)	Clothing
15 (13.6%)	Structures (buildings, bridges, ruins...)
12 (10.9%)	Warning or signage (SOS with stones on the ground....)
10 (9.1%)	Subject - standing -
9 (8.2%)	Other…
8 (7.3%)	Water (wells, streams, rivers, rafts, ditches, fountains...)
4 (3.6%)	Footprint (human, animal, artificial)
3 (2.7%)	Drainage (ditches, road underpasses, manholes,...)
2 (1.8%)	Vehicle (car, bicycle, motorcycle, quad...)
2 (1.8%)	Animal (dog, cat, cow, sheep,…)
1 (0.9%)	Subject - lying down -

Table 2. Reported clues by category.

4 ANALYSIS

4.1 Capture of the images

For the search, 4 sectors were mapped, with a total area of 206 hectares. To photograph these sectors, 10 take-offs were completed throughout the approximately 39 hours that the mapping process lasted. The drone travelled about 80 linear km in a time of 6 hours and 8 minutes, with an average speed of 19.3 km/h. The average flight duration was 25 minutes per take-off. In total, 4932 photos were taken, occupying 91.3 Gigabytes on the server, and covering a total of 2141 hectares.

From these data, it can be deduced that 0.8 ha/minute were photographed, that 24 photos per hectare were taken, that each photo occupies an average of 320 Megabytes per hectare and that, due to overlapping, 10.4 hectares were captured per real hectare mapped.

4.2 Organization of the images

The 4932 uploaded photos were grouped into 461 lots. The search manager decided that 327 lots (73%) would have the highest priority and 134 lots (the remaining 27%) would have a secondary priority, that is, not to be reviewed while there were pending highest priority lots. This decision was made by the search manager, considering the probability of finding the subject together with the difficulty of the orography, repeating the search in some take-offs to increase the possibility of finding clues.

The lots were defined with 15 to 20 photos each, depending on the area covered by the photographs: a larger area, due to a higher flight height, implies a longer review time, thus reducing the number of photos per lot. The maximum number of 29 photos in one of the lots was due to a bug in the tool: instead of dividing the rest of the photos equally among all the lots, they were all assigned to the last lot.

A total of 466 lots (101.1%) were reviewed. This lag is due to the fact that 5 searchers had to abandon the analysis of a lot that they had been assigned. In that case, if it spends too much time down, the search manager assigns the lot to another searcher, so the review process is counted twice.

The total area reviewed was 4282 ha. Since a total of 226 hours and 52 minutes were spent, the review rate was 0.3 hectares per minute, so it is possible to approximate the review of 1 hectare every three minutes. If we consider the 206 hectares mapped, the

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speed in this case was 0.015 hectares per minute or, in other words, one hectare was reviewed every hour and 5 minutes. This difference was due to the overlap with which the photographs were taken. Generally, each point of the mapped terrain appears in four photographs recorded from four different angles, bringing several advantages. In addition, some areas have been checked twice, which greatly increases the review time, but also increases the possibility of finding a clue and, above all, not leaving anything important without review.

4.3 Work developed by searchers

53 searchers, from different fire services, participated, analysing the 466 lots of photographs. On average, each searcher reviewed 8.8 lots (SD: 10.3). There is a large standard deviation, since there were 4 searchers who analysed more than 30 lots, while 22 searchers analysed 4 lots or less. It should be considered that some searchers used their free time to analyse images.

Regarding the time spent by searchers on analysis, the average is 4 hours and 17 minutes (DS: 4:22), with a maximum of 19 hours and 12 minutes and a minimum of 32 minutes. Regarding the time dedicated to analyse each lot, on average, it was 37.5 minutes (SD: 17.7), with a maximum of 87 minutes and a minimum of 8. This diversity of data has several aspects to consider: during the analyses, the virtual searchers could temporarily abandon it and continue later. This is quite common when the searchers are on duty and having to go out or answer a call. Regarding the minimum time, there was a case where, due to an error in the tool, the same lot was assigned several times to the same searcher. In this case, they did not review the same photographs again and the analysis time appears to be clearly reduced. Analysing the time spent by each searcher in the analysis of each lot, 32 (60.4%) of the 53 are between 20 and 50 minutes per lot, only 9 (17.0%) spent less than 20 minutes and 12 (22.6%) spent more than 50 minutes with each lot.

4.4 Devices used and fatigue

Analysing the answers that the searchers gave to the survey included at the end of the review of each lot, we could analyse the devices used.

As previously indicated, the average size of the screen is about 20 inches and, grouping by size, it was observed that most of the searches (202, 51%) were developed with monitors between 17 and 27 inches. In 165 searches (42%), screens smaller than 17 inches were used, some of them (54, 14%) were below the 15 inches. In the group of the biggest screens, it could be observed that 28 (7%) were larger than 27 inches. A limitation of these results is that there were 71 searches in which this question was not answered.

Analysing the resolution of the screens used, the average was 1920x1080 (DS: 606x333) with a maximum resolution of 3840x2160 and a minimum of 1024x768. In this case, the vast majority (263, a 56%) had a resolution below 1920x1080 (Full HD), with 40 analyses (8% of the total) having a resolution of 1280x1024 (XVGA) or lower. Only 54 of the searches (12%) were performed using devices with a resolution over the 1920x1080. Since the resolution was calculated by the tool automatically, this information was available for all searches.

Regarding fatigue, as previously indicated, the mean was 2.2 (SD: 0.9). A large majority (259, 64%) indicated that their fatigue was little or none, and only one searcher indicated an extreme fatigue at the end of a review process. The degree of fatigue was not indicated in 61 lots. No obvious relationship was found between fatigue, resolution and monitor size. On the contrary, it seems that fatigue mostly depended on the complexity of the scenario to be analysed, as some images, such as Fig. 1, were much more complex than others, as Fig. 4.

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Fig. 4. Aerial image, captured by drone, with very low complexity

4.5 Clues found

110 clues were reported and 19 of them were repeated. The appearance of these repetitions is a good sign, since two or more searchers had found the same clue, which increases its interest.

Throughout the search, the criteria for reporting signs from the PMA clearly evolved, according to the updates of the available information. For example, at the end of the search, it was decided not considering clues related to wells, ditches or similar structures. In this way, 44 clues (40%) corresponded to possible objects that the missing person could have lost and 16 (15%) corresponded to the possible trail left by the subject. In only one of the cases (0.9%), a clue related to a human silhouette on the floor was reported. Finally, after their exhaustive review, the 110 clues were discarded.

5 CONCLUSIONS

The maturity of the described graphical tool, currently under development, can be considered sufficient to be used in real cases. This is also possible thanks to the fact that several virtual searchers training sessions had been carried out since September 2019 [20].

The use of this tool made it possible to manage all the graphical information captured, distribute it in lots of images to be analysed by searchers, quickly identify possibly relevant clues, mark them for later review, geographically position them and disseminate the relevant information to the participants in the search.

With this methodology, it was possible to respect the social distance required by the COVID-19 protocols and guarantee the safety of all participants, regardless of the orographic and/or weather conditions during the search, in addition to the possibility of optimizing different types of resources.

In the described search, the collaboration between services was very important, expanding the search capacity and, therefore, the probability of detection, since geographical proximity was not necessary to be able to detect clues digitally.

On the other hand, this search methodology allows to continue searching at night and/or during days with adverse weather conditions, being compatible with other resources (it is not incompatible with the activity of the canine units or the searchers on foot).

Another great advantage, detected during the use of this methodology, was the creation of a georeferenced snapshot of the moment in the precise moment in which the images are captured. With it, it is possible to continue searching and locating clues even if the

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search scenario changes later. For example, if a relevant clue is detected in a photograph, it would be possible to look for it in situ, even if it had subsequently been covered with water, snow, volcanic ash, etc.

It should also be considered that this methodology does not contaminate search scenarios, something that can be a key aspect in police investigations.

Although no obvious relationship was found between fatigue, screen resolution and monitor size, it will be necessary to continue analysing the data collected in future operations, in order to define the optimal environment for the search.

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