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Near Real-time Privacy Protection: Automated Location-dependent Video Blurring in UAV live-streams

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Abstract

In today's world, privacy is becoming a major concern, especially with the use of drones for surveillance and recreational purposes. This paper presents a novel approach to privacy protection in UAV live-streaming by introducing an automated video blurring system that operates in near real-time, replacing time-consuming operations in the post-processing stage. Our method leverages the Scale Invariant Feature Transform algorithm to match live footage with a pre-constructed aerial template image, enabling the blurring of private properties in near real-time, allowing our UAV greater freedom of mobility whilst preserving the privacy of residents at ground level. This solution aligns with the EU's General Data Protection Regulation (GDPR), balancing utility and privacy rights. This proposed framework has the potential to significantly aid the UAV industry by providing a practical tool for privacy preservation during aerial surveys and recreation drone flights.

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Keywords: UAV; drone; privacy; GDPR; SIFT; real-time

1. Introduction

The motivation behind this work came from planning an aerial site survey using Unmanned Aerial Vehicles (UAVs), in two different geographies: Karachi, Pakistan and Hasselt, Belgium. The first survey had no regulatory requirements,

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while the second had significant regulatory conditions to meet before the planned flight. This led to the idea of "Creating a privacy-preserving system that aids the UAV pilot in meeting the EU regulatory requirements."

Recently, the optical sensors or cameras used in UAVs have become significantly inexpensive while the quality has improved remarkably, leading to potential privacy infringement of citizens when used in an urban setting. In parallel to this, the EU introduced the General Data Protection Regulation to standardize the use of public data and protect citizens' privacy (Cusick, 2018). Since May 25th, 2018, the GDPR has been implemented across all 28 EU member states. The GDPR incentivizes businesses to adopt modernization while collecting personal information (Tikkinen-Piri et al., 2018). The recent GDPR legislation has sparked an extensive debate regarding the use of drones in surveillance and their future.

This research potentially addresses the privacy concerns associated with EU commercial or recreational UAV flights. The methodology uses a near-real-time approach to automate the anonymization of private properties, reducing the need for manual intervention during a post-processing stage.

2. Related Literature

Considering the recent GDPR legislation, there's been a surge of research on privacy protection, especially on UAV systems. Table 1 lists down this recent debate and discusses the findings of these studies.

Table 1 recent literature on EU GDPR legislations and UAV.

Article Title	Authors	Year	Key Findings
Impact of Drone Regulations on Drone Use in Geospatial Applications and Research: Focus on Visual Range Conditions, Geofencing and Privacy Considerations	Alamouri et al. (2023)	2023	Discusses EU drone regulations' impact on privacy in the geospatial sector and analyzes the impression of these laws on the overall viability of UAV-based applications. The author also surveys the opinions of drone technology users, revealing mixed opinions on the new rules and potential challenges.
The Governance of Unmanned Aircraft Systems (UAS): Aviation Law, Human Rights, and the Free Movement of Data in the EU	Pagallo and Bassi (2020)	2020	This author examines the framework established by EU regulation 2018/1139 for civil aviation, which devolves ruling controls to both the European Aviation Safety Agency (EASA) and the European Commission. The article also discusses the impact of GDPR's impact on UAV governance, emphasizing on the principle of accountability and balance between top-down and self-regulation. In addition, it explores the EU's practices for legal experimentation and coordination systems as a model for UAV governance.
UAS, Data and privacy protection within the European Union: The case of Greece	Sansaridis (2020)	2020	The article examines the EU's data protection framework and Greek Data Protection practices in cases related to manned and unmanned aviation. It also discusses the challenges anticipated in response to the GDPR and recent EU legislation for UAVs.
What Does a Drone See?: How Aerial Data Resolution Impacts Data Protection	Ryan et al. (2019)	2019	In this study, the authors adopt a technical approach to identify the impact of spatial resolution of UAV-mounted sensors for aerial surveys. A methodology for objectively measuring the resolving power of Phantom 3 Professional (P3P) and Phantom 4 Professional (P4P) drones. Experiments were conducted by conducting surveys at an altitude of 30 meters using P3P and 50 meters using P4P drones to demonstrate the amount of personal information captured. The study recommends the methodology for survey design to minimize the risk of capturing personal data.
The Design of GDPR-Abiding Drones Through Flight Operation Maps: A Win–Win Approach to Data Protection, Aerospace Engineering, and Risk Management	Bassi et al. (2019)	2019	The authors develop a GDPR-compliant flight planning tool aligning promoting the principle of privacy by design for drones. The author also puts a special emphasis on the risk management during drone flights.

In the context of UAV-captured aerial footage, researchers have tried to quantify the volume of personal data captured during a drone flight. These articles have focused on ground sampling distances, 3-dimensional reconstruction accuracy, and radiometric data quality. (Draeyer & Strecha, 2014; Kedzierski & Wierzbicki, 2015; Küng et al., 2012; Meißner et al., 2017). Given the ever-increasing advancements in sensor technology, privacy protection methods are gaining the attention of researchers. Bassi et al. (2019) developed a flight planning tool by adopting the concept of "privacy design." This flight planning tool assists UAV pilots in finding the most suitable air corridors for their drones while considering privacy concerns and regulations of that locality. The authors also investigate and discuss the risk management aspect of drone operations, advocating for proactive strategies to protect personal data before the drone takes off.

Another area where privacy protection of non-participating citizens becomes quintessential is video recording for surveillance and entertainment purposes. Barnoviciu et al. (2019) created a solution that uses AI to anonymize video data. They combined a You Only Look Once (YOLO) based object detection algorithm with blurring filters to detect and blur human faces. The authors claim the system is scalable, does not require hardware modifications, and practically adheres to the EU's regulatory framework.

The discussed state-of-the-art systems have limitations that our proposed research aims to address. Our system offers the drone pilot more autonomy, mobility, and enhanced spatial coverage compared to the existing solutions. The flight planning approach used by Bassi et al. (2019) constrains the drone movement, which could eventually lead to the loss of crucial information during the aerial survey. On the other hand, the YOLO-based blurring solutions are computationally intensive and could record personal data in instances where detection accuracy is lost or where, despite detection, the system still records personal information (e.g., a person-object being detected in private property). Another key issue with a YOLO-based solution is that it would not be able to distinguish between public and private properties and, hence, will record personal information. Therefore, these state-of-the-art applications are not viable in the context of privacy protection for private property. Our proposed system tackles this problem and allows the drone pilot more flexibility and the freedom to fly in any direction compared to the flight planning approach. The automatic blurring mechanism is less computationally intensive since private properties are predefined.

3. Methodological Framework

3.1. Experiment Specifications

The proposed workflow eliminates the need for manual blurring, often done during the post-processing stage. We propose an automated framework using the Scale Invariant Feature (SIFT). The video is broadcast to the computer using a Real-Time Messaging Protocol (RTMP) service over an Internet Protocol (IP) address. This IP is fed as an input into the Python environment using OpenCV and processed frame by frame. An orthorectified georeferenced image from a UAV or a very high resolution (VHR) satellite image from Google Satellite is used for template matching. The working methodology slightly shifts based on the source of the template image. In the case of a UAV-based template image, the workflow is simpler; the key points between the template and input frames are matched, and the geographical projection from a template is replicated onto the input frame. In the case of VHR imagery, the input frame is downscaled before feature matching. This additional process is done due to the higher resolution of UAV cameras compared to satellite imagery's relatively lower spatial resolution. After the feature matching in both cases, a blurring filter is applied to the predefined private properties through a shapefile developed from officially published parcel boundaries.

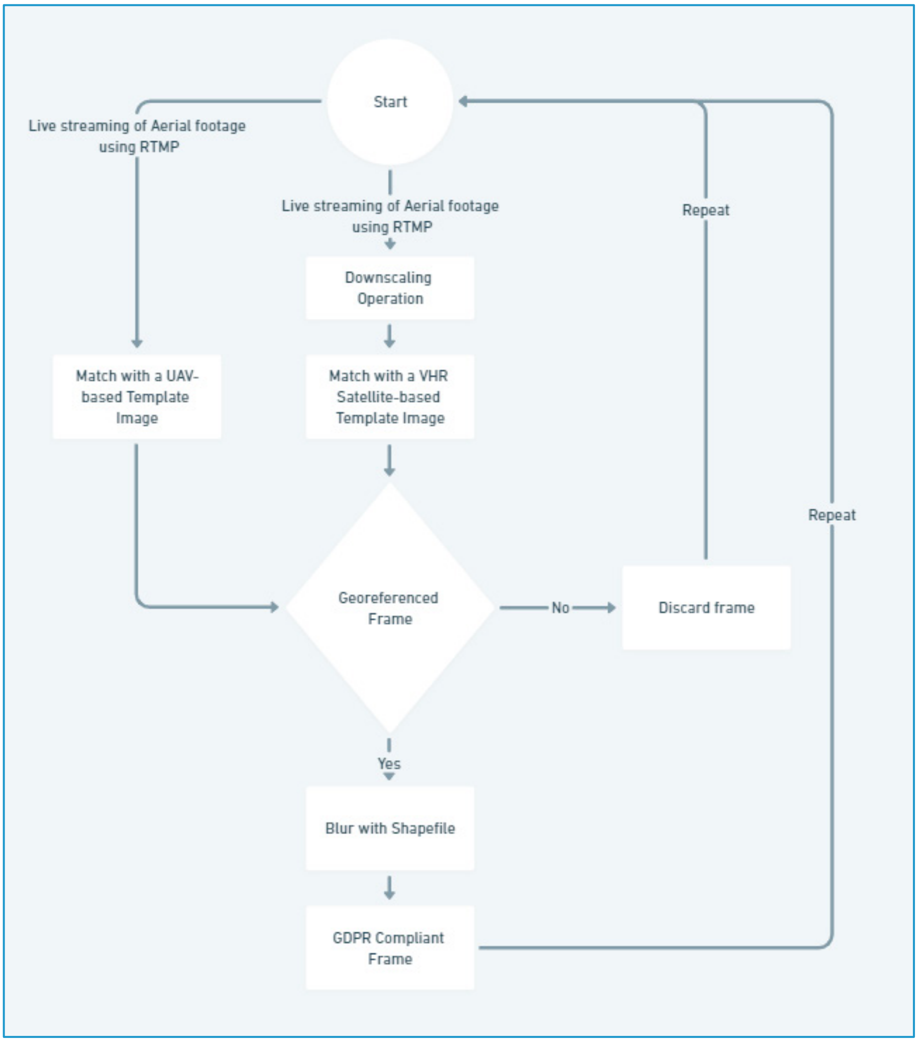


Fig. 1. Methodological framework of the study.

3.2. Development of Template Image

For this experiment, template images from 2 different sources were utilized, as illustrated in Fig.2. The first experiment involved a drone flight from DJI mini 3 pro flying at 120 meters altitude and performing an aerial survey at 48-megapixel camera settings. The camera angle was set to 90 degrees to avoid any angular occlusion. A visual line of sight was maintained throughout the flight, and multiple images were taken to create orthomosaics over a wider area. Ground control points (GCPs) with known coordinates were plotted onto this image, and a projection system was implemented using GIS software. Similarly, another template image was prepared using images of the same location from Google Earth.

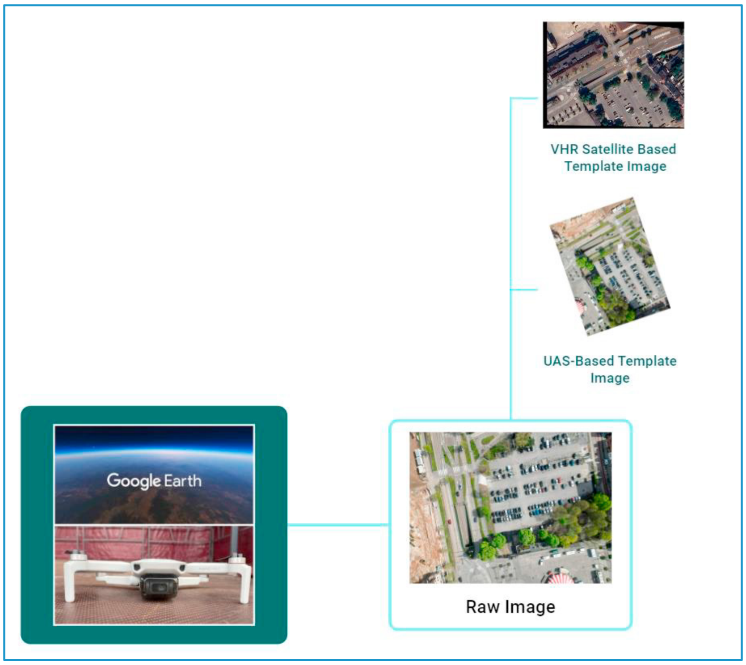


Fig. 2. The figure illustrates the process involving the preparation of a template image using GIS software.

3.3. Live Streaming of Drone Footage

In this proposed framework, a Real-Time Messaging Protocol (RTMP) was used to broadcast the live stream from our UAV to a computer system that further processes the video stream. RTMP is a popular protocol for sending live-streaming audio and video data online. It starts by capturing the audio and video; then, an encoder converts this data into smaller packets. These packets are sent to a streaming server, which then processes and sends them to the viewer's device. To ensure that the packets arrive in the correct order without any error, RTMP keeps a constant connection over TCP (Nurrohman & Abdurohman, 2018). A DJI Mavic Mini connected to a lightweight communication server, i.e., Monaserver, was used with an MSI GL63-8RE laptop equipped with an 8^{th} Generation Intel Core-i7 processor and 16GB of RAM.

3.4. Aerial Template Matching and Automatic Blurring of Private Properties

To implement location-based blurring, it is important to match the pixel coordinates of the footage with real-world geographical coordinates. This was achieved by utilizing a Scale Invariant Feature Transform algorithm created by Lowe (2004), available in the OpenCV library. It detects consistent features between two images, resilient to rotation, scaling, and lighting variations. SIFT identifies the most stable key points and assigns a dominant orientation. Then, it creates a 128-dimensional descriptor for each key point, capturing detailed information about local image gradient magnitudes and orientations. A descriptor is formed by dividing the region around the key point into smaller subregions and creating histograms of gradient orientations. SIFT can identify key points across various images using these descriptors, facilitating functionalities such as object detection, merging images, and creating 3D models (Nixon & Aguado, 2020).

Fig. 3. (a) is the template image whereas (b) is the zoomed in area with assumed restricted property for near real-time blurring. Fig.3(c) shows the resulting image from another temporal period.

After feature matching between the two images, the geographical coordinates of the matched key points are projected onto the target frame, as shown in Fig. 3. To ensure the features matched are of good quality, a ratio test is applied to the detected features by calculating Euclidean distances between them (the lower the distance, the higher the accuracy of the match). A blurring operation is applied after the pixel coordinates with real geographical coordinates. To blur private or restricted areas, the blurring functionality of OpenCV was used, with a kernel size of 100. The private or restricted properties were pre-defined using ESRI shapefile format and dynamically implemented on each georeferenced frame. This entire process is repeated until the live stream is disconnected.

4. Results, Discussion & Conclusion

4.1. Experimental Results

The methodology was assessed qualitatively and qualitatively across various conditions and scenarios. The georeferencing quality has the most implications for the precise projection of blurring; therefore, a quantitative analysis of georeferencing was carried out. The accuracy assessment was conducted by plotting 4 GCPS on the output frame and comparing the deviation of each GCP from the source maps (discussed in Table 2) using QGIS software. The X and Y coordinates of each GCP on the source image were compared with that of the resultant georeferenced frame, and residual errors of each GCP were calculated. The experimental results showed minimal deviations with a total RMSE of 2.138, confirming the positional accuracy of the proposed method.

Table 2 Quality assessment of the georeferenced frames.

X-Source	Y-Source	X-Map	Y-Map	X-Residual	Y-Residual	Total RMSE
243162.938	5648764.648	243162.795	5648764.723	0.143	-0.074	2.138
243213.846	5648749.310	243213.474	5648749.227	0.372	0.083	
243226.287	5648713.321	243224.668	5648714.646	1.620	-1.325	
243173.320	5648750.083	243173.354	5648749.943	-0.035	0.140	

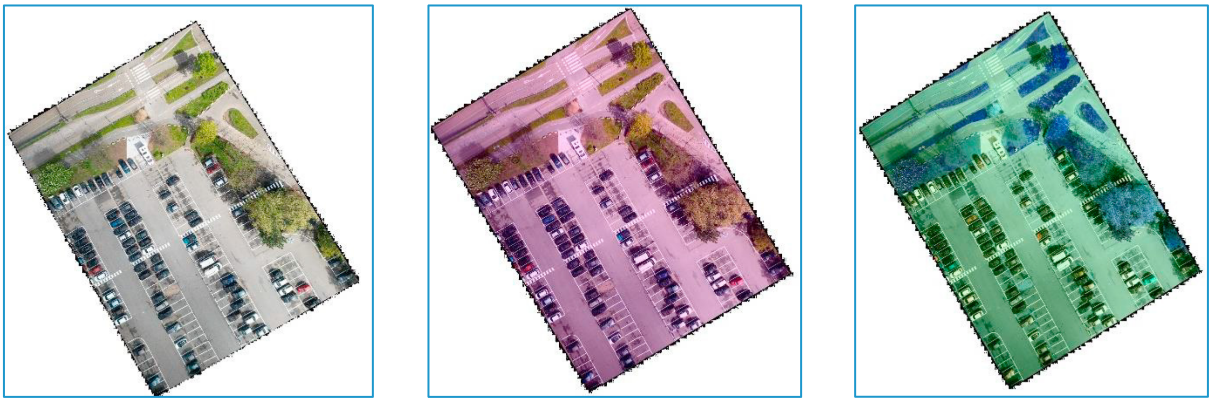
The most noteworthy outcome of this experiment was that the method performed best in daylight around areas with diverse topographic features as key points. SIFT is known to withstand variations in illumination levels causing changes to pixel intensities; therefore, it was able to handle this situation well. Table 3 discusses the experimental findings in different real-life and simulated scenarios.

Table 3 the tables showcase a qualitative analysis of the research findings.

Condition	Performance Good	Fair	Poor	Remarks
Daytime	✓			Given that the area covered has a diverse topography and generates enough key points to match.
Night-time			✓	Without natural illumination, the algorithm struggles to find key points.
Decreased Topographic Diversity		✓		Requires threshold adjustments for the minimum key points required to georeference an image.
Angular Changes			✓	The method is affected by angular obscurity. The major limitation of this workflow is that the camera angle at which the input frame was taken must be identical to the template image.
Multi-UAV flight	✓			The workflow works great with mosaicking multiple simultaneous inputs from multiple live streams. The only constraint is the topographic diversity.

4.2. Further discussion of the results and limitations

The results of our experiment are promising, as SIFT proves to be resilient to seasonal and daylight variations, making it ideal for real-life application. To test the practicality of the proposed method and SIFT's resilience to seasonal variations, several daylight scenarios were simulated using the same area of interest, as shown in Fig. 4. The synthetic images of the same locations were generated by adjusting the tint and hue through photo editing software, and the feature matching was successful in each case.



a) Original Daylight b) Synthetic Image # 01 (Tint Adjustment) c) Synthetic Image # 02 (Hue Adjustment)

Fig. 4. Assessment of workflow in simulated light conditions.

While the results of this methodology are promising, certain limitations prevent SIFT from producing the most optimum results in some instances. The first major limitation of this workflow is the lack of angular flexibility, which means that SIFT cannot match frames taken at off-nadir angles greater than 0 degrees. The second major impediment observed was in images lacking topographic diversity. The northern region of the image in this experiment has diverse geographic features, providing ample consistent key points to perform feature matching. Another limitation observed was the additional adjustments required for the satellite-based template images. With the VHR satellite-based template image, the workflow required additional adjustments, such as downscaling of the input frame and ratio testing to filter and calibrate suitable feature matches. Another noticeable limitation is the delay experienced by the broadcasting protocol. A faster broadcasting protocol could benefit the overall processing speed and be crucial to developing a live and real-time solution.

4.3. Future Research Directions

Following the essentiality of feature matching and georeferencing in this workflow, a comparative study using alternative feature matching algorithms like Speeded Up Robust Feature (SURF) and Oriented FAST and Robust BRIEF (ORB) is needed with a focus on matching quality and processing speed. The other underexplored aspect is retrofitting this methodology to blur footage at oblique angles. This will enable a system that offers more flexibility in different scenarios.

In addition to methodological improvements, we aim to explore the use case involving satellite imagery further. We plan to gauge the spatial and radiometric resolution influence of different high-resolution satellites on our proposed methodology. Furthermore, the workflow has wider implications; therefore, we plan to explore additional prospects for this system.

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