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Abstract. Accurate and repetitive observation and quantification of the shoreline position and the coastal feature are essential aspects of coastal management and planning. Commonly, the dataset associated with coastal observation and quantification is obtained with in-situ coastal surveys. The current methods are mostly quite expensive, time-consuming, and require trained individuals to do the task. With the availability of the off-the-shelf low cost, lightweight, and reliable Unmanned Aerial Vehicle (UAV) with the advances of the algorithms such as structure-from-motion (SfM), UAV-based measurement becomes a promising tool. Open SfM initiative, open topographical database, and UAV communities are the enablers that make it possible to collect accurate and frequent coastal monitoring and democratize data. This paper provides a review and discussions that highlight the possibility of conducting scientific coastal monitoring or collaborating with the public. Literature was examined for the advances in coastal monitoring, challenges, and recommendations. We identified and proposed the use of UAV along with the strategies and systems to encourage citizen-led UAV observation for coastal monitoring while attaining the quality.

Keywords: citizen science, UAV, coastal monitoring

1. Introduction

There are two major sources of open data, the government-produced and community-created data, the latest can be considered as citizen-science [1]. Citizen science promotes the participation of the citizen in producing and disseminating scientific knowledge to address real-world problems. Citizens are involved in generating, preparing, and processing scientific observations and detailed measurements [2]. They commonly produce knowledge as a community or citizens' networks that act as observers [3]. Citizen science has contributed to some extent of scientific research such as environmental monitoring [4], astrophysics [5], participatory research [6], and natural resources management [7].

Most of the world's coastlines have limited data observation, in contrast to the coastal zone where the megacities are located [8]. Sea levels are rising due to global warming, and this trend is anticipated to continue and increase in the next decades [9], resulting in more frequent coastal flooding, material asset destruction, and an elevated risk of human death [10]. These effects will be accentuated by the great concentration of activities, services, and people in coastal cities. The coastal zone population has surpassed 600 million people worldwide, with migration trends predicting a rise to more than 1 billion by 2050 [11]. To our knowledge, few beaches have collected up to decades of coastal dynamics dataset such as Narrabeen-Collaroy in Australia [12], the Dutch annual coastal monitoring [13], daily beach profile monitoring in Hasaki Japan [14], and in Duck USA [15].

Unmanned Aerial Vehicles (UAV) are known appropriate for high-resolution topographic and geomorphic change detection [16]. UAV's accuracy is comparable to Terrestrial Laser Scanning (TLS), Aerial Laser Scanning (ALS), Real-Time Kinematic (RTK) or differential GPS (DGPS) and the total station. Some research show that UAV (consumer-grade) with the Structure from Motion (SfM) photogrammetric method could attain vertical accuracies and horizontal accuracies in the order of a few centimeters [17].

In this paper, we explore the possibilities and strategies to use citizen science for coastal monitoring. The focus of coastal monitoring is on the possibility of crowd-sourced aerial monitoring with the consumer-grade UAV. We provide a review of several examples on the verdict of crowd-sourced mapping, publicly available satellite imagery influences to coastal management in the context of data availability that influences the understanding of the coastal dynamics, strategies that are likely possible to democratize and crowd-sourced coastal monitoring dataset as inspired from the established open-source mapping project.

2. Material and Methods

This paper uses a systematic literature review to explore the studies on coastal monitoring with UAV. First, the literature review was conducted to explore the question "how is the possibility of the citizen-led coastal monitoring by using the off-the-shelf UAV?". Second, the Scopus-based search was conducted using the keywords "UAV AND Coastal AND Monitoring" and "citizen AND science AND coastal AND monitoring," resulting in 267 and 156 documents, respectively. Third, the screening process to eliminate papers based on the relevancy by reviewing the abstract and methods. Fourth, the most relevant publications were included in the review.

3. Results and Discussion

3.1. UAV as a high-resolution coastal monitoring tool

UAV measurement, particularly the passive measurement with the photogrammetric method, offers easy handling to plan and conduct the topographic measurement aided with proper Ground Control Points (GCP) or is already equipped with RTK-GPS positioning to ensure the topographical measurement accuracy. Recently, some UAVs have been equipped with a high-precision navigation system that allows automatic flight and is almost independent of the ground control station [18]. The UAV-based topography data has an advantage on the high resolution of up to 2 cm and the low uncertainty up to ± 5 mm comparable to the TLS with reduced cost and time of acquisition [19]. Moreover, several studies have demonstrated the accuracy, repeatability, and usability of UAVs for coastal monitoring. The studies range from monitoring the multi-temporal coastal topography in a very high-resolution (centimeter) aided with DGPS [20], tidal inlet topography monitoring [21], monitoring and assessing post-storm coastal erosion in a full coastal embayment [22], and topographic survey and geomorphic change detection in the complex beach [16].

Basically, there are four types of UAV airframe, i.e., single-rotor, multi-rotor, fixed-wing, and fixed-wing hybrid Vertical Take-Off and Landing (VTOL) [22]–[24] (Figure 1); the latest is the merging of fixed-wing that taking advantage of the rotor that makes it possible to take-off vertically. Depending on the field setting; each has its particular advantages; for instance, fixed-wing is typically long-range that well suited for stripped and relatively narrow coastline, while rotor-type is more flexible on terrain but limited in range and flight time. The off-the-shelf version of UAVs is typically lightweight in the order of a kilogram and very easily transportable during surveying.

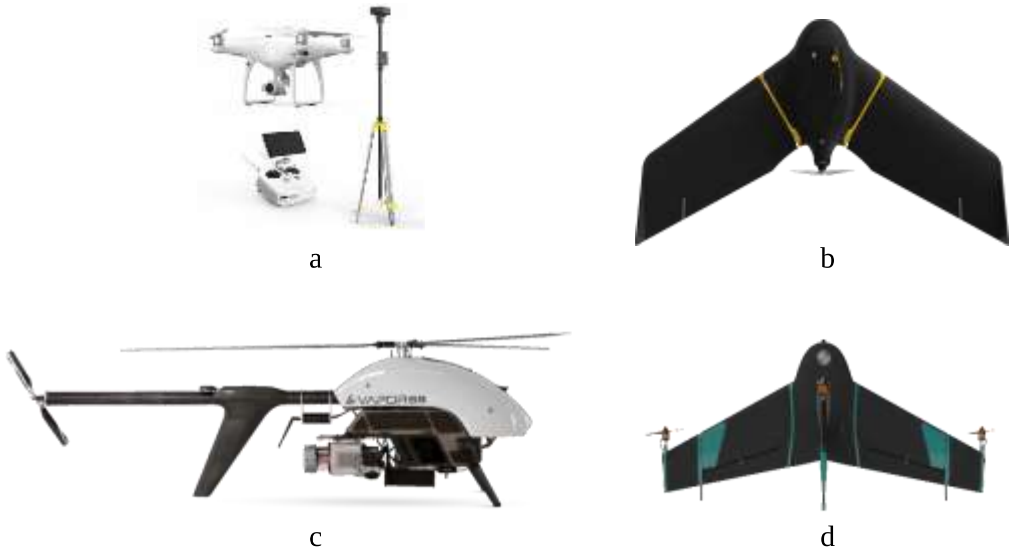

Figure 1. Types of mapping drone: a) multi-rotor drone, DJI Phantom 4 RTK (DJI, Shenzen, China), b) fixed-wing, eBee X (senseFly, Cheseaux-Sur-Lausanne, Switzerland), c) single-rotor helicopter, Vapor 55 UAV Helicopter (Skyline UAV, New South Wales, Australia), and d) fixed-wing hybrid VTOL, Marlyn UAV (Atmos, Valkenburg, the Netherlands).

SfM photogrammetry is a technique that has been used for decades to derive three-dimensional structures from a set of overlapping two-dimensional images. The original idea was presented back in 1979 [25] and the algorithm of the object recognition of automated feature-matching that applied the Scale Invariant Feature Transform (SIFT) in 1999 [26]. Fundamentally, there are five steps to generate the Digital Surface Model (DSM) and orthomosaic derived from SfM photogrammetry (Figure 2). Step 1, the corresponding features of the overlapping images were matched, and measure the distances between the features–the SIFT algorithm is the key to this process. Step 2, the individual camera positions, orientations, focal lengths, and relative positions of the corresponding features were calculated, called bundle adjustments. This step explains the SfM term, where scene "structure" refers to those parameters and "motion" refers to the camera's movement. Step 3, a dense point cloud and the 3D surface were determined based on the known camera parameters and the SfM points as the ground control called multi-view stereo matching, which typically created 100-1000 points per m^2. Step 4, converting the point cloud into a real-world geographical coordinate system, known as georectification. Step 5, generated DSM and orthomosaic for texture mapping purposes. Several well-known proprietary and open-source software include Agisoft Metashape, Pix4D, VisualSFM, and Open Drone Map [27].

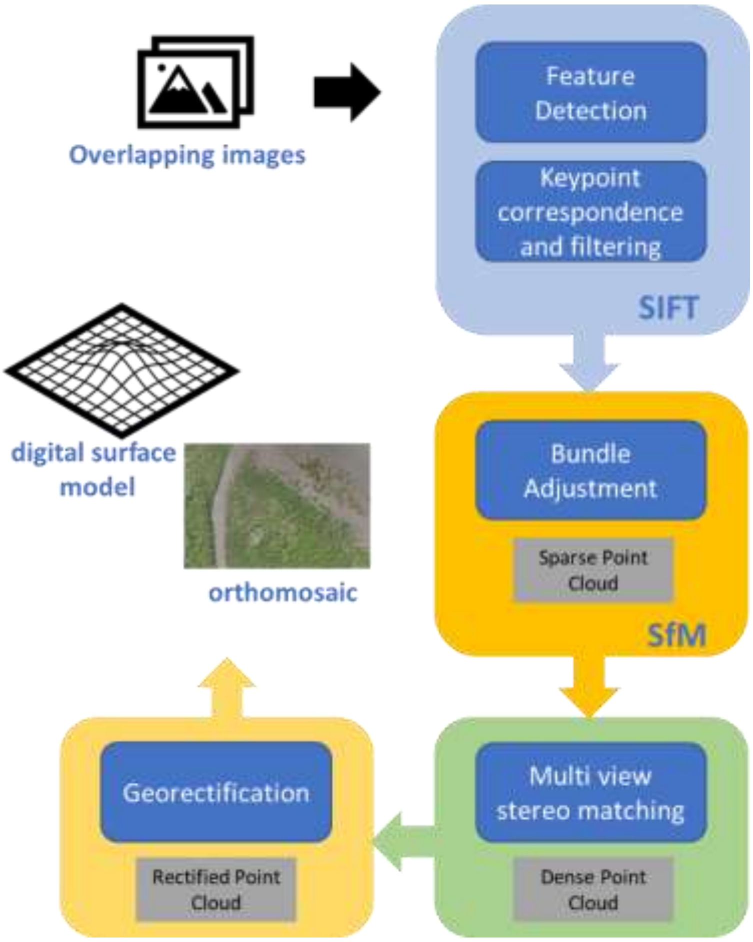

Figure 2. Steps of generating DSM and orthomosaic from SfM photogrammetry.

A typical workflow of processing two-dimensional images into DSM or DTM can be followed as 1) flight planning, 2) GCPs identification, 3) generation of the point cloud, DSM, and orthomosaic, and 4) point cloud noise-cleaning as in Figure 3. In topographical measurement, it is favoured to fly the UAV at the altitude of 40 m to 60 m with an overlay of at least 80% front overlap and 75% side overlap. It will increase the accuracy even better if the UAV is set to capture an oblique image of the objects, facing toward the inner circle of the object by not including the horizon. This feature is known as 3D mode in DroneDeploy [28]. Other well-known flight planning apps are DJI GS Pro and Pix4D Capture. GCPs are necessary for the UAV system that has no RTK module on board. In a system that requires them, the well-distributed GCPs play an important role, not only for georeferencing but also to avoid the dome or bowl effect [29], [30]. Practically, the minimum geotagged GCPs should be five, arranged in the corner and middle of the area of interest; however, the size of the surveyed area should be considered. As explained above, point cloud, DSM, and orthomosaic are the derivative product of SfM photogrammetry. Quality control and noise cleaning are important steps since aspects such as water reflection, light condition, low texture, and contrast of the bed surface affect the products and will add noise and uncertainties [17], [31], [32].

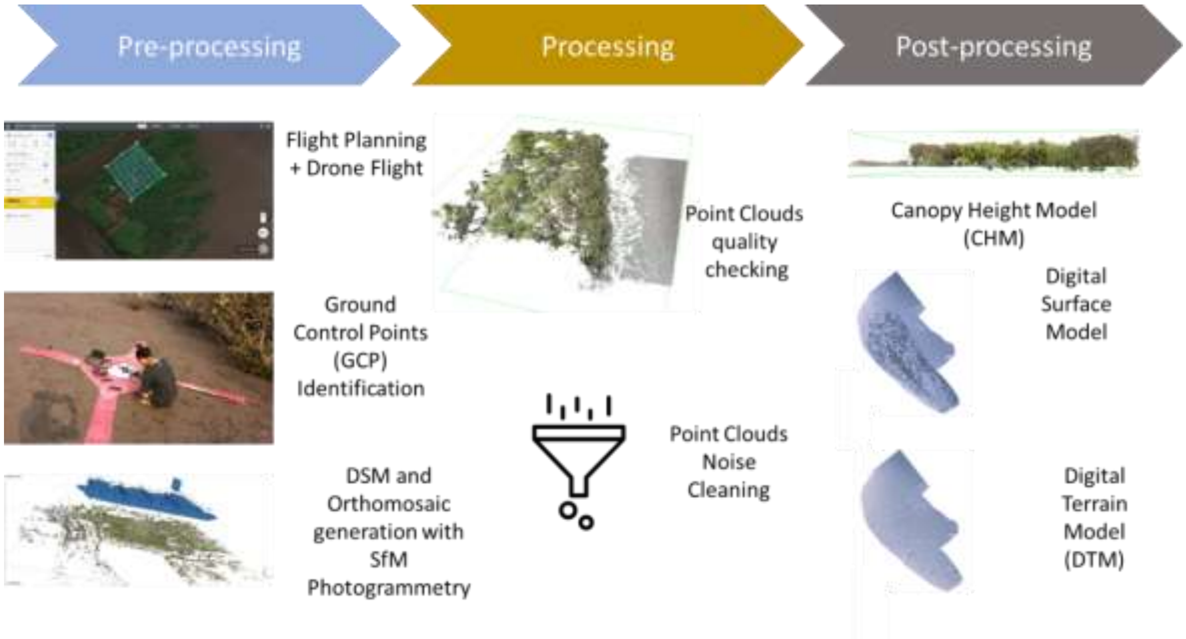

Figure 3. A typical workflow of UAV-based SfM photogrammetry generation and processing, modified from Beselly, et al., 2021.

3.2. Looking at the citizen science in mapping
Crowd-sourced mapping has improved the official map, especially in areas where government-produced data are lacking or sparse. One of the notable crowd-sourced maps is the OpenStreetMap (OSM) [1], [33]. OSM data was created by the contributors or volunteers that used aerial imagery, GPS devices, and low-tech field maps to validate the accuracy and the up to date of OSM [33]. OSM map added valuable information in the micro-level with a high level of local relevance. It has also become a platform for mapping areas of humanitarian interest, such as areas in crisis due to the disaster that requires an up-to-date map through the HOT-OSM team. However, despite of the benefits, as open source project, there remain challenges, such as volunteer coordination, funding, data license, and strategic development. The US State Department's MapGive program supports OpenStreetMap. In OpenStreetMap, contributors map infrastructure data such as road lines, building footprints, sites of services and amenities, land uses such as fields or industrial regions, and many others [34].

3.3. Citizen science for coastal monitoring and problems
There have been few citizen-science projects in coastal monitoring. One of the few is the coast-snap, where crowd-sourced coastal imaging stations were placed, which enable people to use their smartphone to capture the current condition of the beach, and the shoreline map was created based on the uploaded images [35]. The station is placed in a specific location and has a specially designed mount to accommodate the smartphone camera. The images were shared to a database by uploading the images to the social media platform (Facebook, Twitter, and Instagram) or email as a JPEG attachment. If posted to social media, the citizen should use a specific hashtag specific to the site, for instance, #CoastSnapMalang to identify and download the images. The workflow is that the original shared images were stamped based on the captured time, georectified based on the several GCPs. The shoreline was detected with the shoreline edge detection technique and corrected for tidal variations. The result of CoastSnap is the time-series of shoreline change and estimation of the beach face slope and has a good correlation in comparison with RTK-GNSS measurement. In the current development, a smartphone app has been developed. Another interesting project is the GeoNadir [36], a crowd-sourced, free, web-based drone images data collection and processing platform. GeoNadir segmented its users

into three categories, drone pilots, researchers, and land and sea country managers. Currently, GeoNadir focuses on a hosting platform that helps users manage, store, and share images with the public.

Considering the lack of coastal datasets and the increasing popularity of off-the-shelf drones, we suggest building a strategy and system to encourage the drone communities to participate in citizen-led coastal monitoring. This attempt is likely possible since most of the tools are available as open-source. In contrast, the main part that hindered the initiative is the standardization of the workflow, ample data storage, and intensive computational power in the processing stage.

To ensure the consistency and repeatability of the workflow, we suggest standardization in every step. First, we suggest designing a default flight mission that should be reused during the data collection. The chosen platform should be free for individual use and allow users to share the flight mission. Permanent GCPs should be defined and geotagged by considering sufficiency for the SfM photogrammetry. Data storage and computational power hindrance are highly likely dependent on the size of the surveyed area. As a rule of thumb, a medium-range computer can calculate around 1000 images in one day, equal to a 5 ha coverage area in the high-quality setting. In this case, local processing by the volunteer is preferable. However, suppose the region of interest requires a lower altitude or has a larger area. In that case, a cloud computation solution can be considered. GeoNadir, for instance, in the future release is planning to provide a complete solution for storing and processing drone images. Local institutions or organizations can also adopt this strategy by developing their cloud computing platform or using public computing resources such as Google Cloud, Amazon Web Service, Microsoft Azure, and Alibaba Cloud. If the storing and processing is done in the cloud platform, the crowd-sourced providers would directly manage the raw and processed data. Regarding this, the crowd-sourced providers should follow the FAIR principles (Findable, Accessible, Interoperable, and Reusable).

To ensure the quality and consistency of the monitoring, the existence of an institution or organization is undoubtedly necessary to consolidate this crowd-sourced project. Lessons learned from the established citizen science challenges require solid coordination in volunteer, funding, and strategic development. As a starting point, universities could take the lead as initiators since they have adequate human resources, access to the tools, and credibility. University can collaborate with local UAV enthusiasts or clubs to start the pilot of citizen-led UAV-based coastal monitoring. University experts can provide the necessary tools for the workflow and training to the volunteers. As the first step, all of the processing can be done locally by the volunteer itself. Soon, with the growing of collaborators, a cloud computing system will be necessary to be developed. However, it depends on the monitoring frequency design. If, for instance, it is decided to have seasonal monitoring, local-based processing is favourable. Thus, it will create a leaner organization whilst still providing more frequent monitoring compared to the traditional. Therefore, it can be a likely solution to encourage citizen participation. When the region of interest is quite decent for medium-range computers, using local processing is preferable. Funding can be reduced to the minimal requirement, and the University can do the processing. Furthermore, a feasible strategic development would be possible.

4. Conclusions

As the off-the-shelve UAVs are getting smaller and popular among consumers that range from hobbyists, enthusiasts, professionals, and academics, the potential for their usage in environment monitoring is plausible. Some methods have been developed with a good agreement of accuracy for topographical measurement compared to the traditional measurement. Several research has shown the benefits of using UAVs on monitoring the environment. UAVs are non-intrusive, high-resolution remote sensing techniques and repeatable to avoid costly and time-consuming field campaigns in remote areas. It makes it possible to quantify the spatiotemporal changes of the environment. It is common sense that the main challenge is the lack of data, focusing on the coastal environment. One of the causes is the nature of the environment (difficult to access, power limitation, and harsh environment). As the government mainly provides the data, we suggest complementing the data gap by employing crowd-sourced or citizen-science-based data collection. By taking inspiration from the citizen-led mapping projects, we recommend initiating a strategy and system to encourage the drone communities to participate in citizen-led coastal monitoring. To ensure the quality and consistency of the monitoring, the standardization of the workflow, data storage, and processing should be considered. University with several advantages such as highly qualified experts, facilities, and credibility is highly likely to lead on this initiative. University can provide training and provide the necessary tools for the volunteers to be advanced as local experts. First, a region of interest with an acceptable area for local processing in a medium-range computer can be selected. Thus, a leaner organization with University as a leader in cooperation with local UAV club enthusiasts and local government can be developed. As a result, funding needs can be reduced, while a feasible strategic development of the organization can be planned.

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