Towards Drone-Assisted Large-Scale Disaster Response and Recovery

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***Abstract*—Major damaging events with many victims or environmental contamination hazards, such as natural disasters, airplane crashes, train accidents or terroristic acts, are shocking events to society. Fast and comprehensive information acquisition of event sites ensures appropriate and safe actions for rescue forces and investigators, and increases resilience of our society with respect to such disorders in the long term. The use of unmanned aerial vehicles, so-called drones, for gathering as much information as possible about the event site to support the whole resilience cycle is a fast and safe way to elucidate such unknown environments. Therefore, an application framework is currently developed by the authors, which aims at supporting decision makers with respect to targeted and safe management of rescue teams and the fast locating of victims, as well as 3D spatiotemporal modeling and simulation of events for forensic purposes. In this work, we present a process chain for 3D reconstruction of event sites using aerial photogrammetry and open source software.**

Keywords–forensic; unmanned aerial vehicle; resilience engineering; open source; 3D reconstruction

I. Introduction

On March the 24th 2015, *Germanwings* flight 4U9525 crashed in the French Alps after a suicidal co-pilot intentionally initiated a controlled ten minutes lasting descent. All 150 people were killed instantly. Located in remote mountainous terrain difficult to access by vehicles, the disaster site is quickly reachable only by helicopter which posed major logistic problems to rescue forces and investigators, especially in the first hours after the crash. Many other similar scenarios, such as natural disasters, pile-ups, train accidents or terroristic acts, pose analogous problems to personnel, whereas locating survivors and bodies, obstructive and dangerous pieces of debris, and sources of toxic or hazardous chemicals is a major concern in this respect. Thus it is of major importance to generate a general picture based on available information about the disaster site–not only with regards to lifesaving, but strategic resource planning as well. However, especially in the first minutes and hours, such information is difficult to obtain [1] [2].

In this work, we present the concepts of a general framework for drone-assisted 3D reconstruction and mapping of disaster sites. Drones (or unmanned aerial vehicles, UAVs) are small and effective platforms for accessing and imaging locations that are difficult or impossible to reach quickly by personnel or helicopters, and are thus of great potential in providing a fast mapping of disaster sites, as well as locations of potential survivors [1] [3]. Additional drone payloads, such as thermal imaging systems, pollutant sensors, and automated GPS-assisted navigation systems, yield an even wider range of applicability and potential in resilience engineering in general (please see the work of Colomina and Molina [4], as well as Horsman [5] for an extensive overview).

Based on a study presented by Püschel et al. [6], which aimed at 3D reconstruction of tourism objects by combining aerial and terrestrial photogrammetry using drones, we designed concepts for disaster site 3D reconstruction and mapping by means of open source software based on aerial images acquired by drones. In this paper, we first provide background and motivation for said reconstruction processes (see Section II), present the photogrammetry software in question and introduce a strategy for drone-assisted 3D disaster site reconstruction, including results obtained by proof-of-concept testing of such. Finally, in Section III, we briefly introduce our drone system

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and its conceptual application to the crash site of Flight 4U9525, demonstrate the proposed strategy's performance in application to the Mittweida water tower which we chose as our object of initial studies, and conclude by prospects of future work (Section IV).

II. 3D Disaster Site Reconstruction

An important task in forensic disaster response and recovery is to gather and process information about event sites (such as crime or disaster scenes) quickly and safely in order to support action planning and well-directed employment of rescue teams on the one hand, and eventually provide data for eventual spatiotemporal reconstruction of such an event on the other. There are various methods for gaining such valuable information, including terrestrial and helicopter- or drone-based large-scale imaging, videotaping or laser scanning. The evaluation of the data obtained by mentioned means and subsequent 3D reconstruction can be realized by utilizing various software packages, either licensed, free or open-source. Although cutting edge in quality and performance, laser scanning systems are costly with respect to operation, maintenance and acquisition (including specialized software for data processing). In contrast, open source software can pose cost efficient alternatives. We here propose a pipeline of open source software for 3D event site reconstruction based on drone-assisted imaging.

The first open source software package within the reconstruction process is Visual Structure from Motion (**VisualSFM**) [7]. Providing both a user interface, as well as command line access for batch integration, VisualSFM is utilized for calculating 3D point clouds of multi-image photographs of an object or area based on Wu's scale-invariant feature transform GPU algorithm [8]. In addition there are further algorithms implemented in VisualSFM, such as Clustering Views for Multi-view Stereo (CMVS) and Patch-based Multi-view Stereo (PMVS) [9] to cluster and condense calculated point clouds. In the process, **CMPMVS** [10] is utilized to refine obtained 3D point clouds, reconstruct object surfaces and compute object textures. The downstream software to VisualSFM and CMPMVS are **MeshLab** [11] and **Blender** [12]. MeshLab can be used for post-processing and editing reconstructed surfaces or refining them from computed point clouds if necessary. Furthermore, multiple object meshes can be aligned and unified to one single mesh. Blender is a 3D graphics and animation software and can be used to import object (.obj) files generated in MeshLab and edit, add, merge, measure, (re-)texture and render 3D objects.

Using this pipeline, valid reconstruction results can only be obtained if underlying images are of good quality and, equally important, coherent in perspective. More precisely, images are required to capture the entire scene from all general view angles including perspective overlaps that ensure determining virtual camera positions in the reconstructed 3D point space and, hence, proper object reconstruction. Therefore, analogous to results presented in [13], drone-assisted 3D site reconstruction is of best quality using this software pipeline if the area in question is captured at a circular flight path from a drone circumnavigating the area. Note that computation time and memory usage are determined by the surface reconstruction process, growing exponentially by the number of images, image resolution, and identified object points.

Initially, we tested the concept using sequences of pseudo-aerial images obtained from **Google Earth**. Images were retrieved along virtual circular flight paths and eventually used for 3D site reconstruction. A schematic of the proposed reconstruction workflow is shown in Figure 1 including an example reconstruction of the *Germanwings* Flight 4U9525 crash site based on 25 pseudo-aerial images [14].

III. Drone-based Image Acquisition

A. The Drone in Use: Technical Aspects and Capabilities

The drone used in our study is a *MikroKopter MK-ARF Okto XL 6S12*, an eight-blade rotary wing drone for multi-purpose utilization. In our set-up the MK-ARF Okto XL 6S12 has a maximum slant range of 4,000 m and a maximum ceiling of 5,000 m above sea level. With fully charged batteries and optimal weather conditions, the drone achieves a maximum flight time of about 45 minutes. Besides present weather conditions, maximum flight time is reduced by hardware additionally mounted to the drone, such as a fixed SLR (single lens reflex) camera. Furthermore, the drone is equipped with a CMOS (complementary metal-oxide-semiconductor) camera whose video feed can be received and post-processed on the ground. Although not-movable around the yaw axes, both the CMOS and SLR camera mount can be pitched and rolled. In combination with automated pre-planned waypoint flight and point-of-interest focusing capabilities, as well as automated camera triggering, the user is thus able to obtain images made in-flight at pre-planned positions and altitudes. Waypoints and trigger events can be set-up and uploaded to the drone using the maintenance and control software MikroKopter-Tool V2.12a.

B. A Strategy for Drone-assisted Disaster Site Imaging

As discussed in Section II, 3D object reconstruction by means of VisualSFM using a sequence of images is only feasible if these are recorded along a circular track around the object. Hence, drone-assisted terrain and disaster site reconstruction utilizing this reconstruction strategy requires an analogous object-camera geometry in the recording process. Therefore, a drone is programmed to fly a nearly circular path around the center of the region of interest, whereas the center is constantly focused by the camera. The appropriate image sequence can eventually be obtained in-flight. As elucidated above, the MK Okto XL 6S12 is capable to realize such a pre-planned flight profile.

With respect to extensive dimensions of some disaster sites (i. e., the crash site of Flight 4U9525 is about 380 m $\times$ 500 m), covering the entire region of interest utilizing a single circular path is unfeasible or even impossible to achieve due to range and flight time limitations. To circumvent these restrictions, a given region of interest can be split in a set of smaller overlapping circles in a straightforward manner (see Figure 2A and B). Obtained image sequences are used for 3D reconstruction of corresponding smaller circular areas which are eventually assembled to a single unified model of the region of interest using MeshLab (Figure 2C and D). Image capturing and site reconstruction can thus also be conducted in parallel. In addition, Figure 2E shows a section of the MikroKopter-Tool's waypoint flight planner employed to the Flight 4U9525 crash site. In this virtual scenario, the drone is programmed to take off at a clearing (waypoint two, P2) which can be reached either by helicopter or by vehicle via an unpaved mountain trail and proceeds around the POI (waypoint one, P1) in a circular manner described by 25 waypoints, whereas the camera is pointed towards the POI throughout the flight. Blue circles visualize three additional circular flight paths required for reconstructing almost the entire crash site from corresponding 3D models.

C. Application

The proposed 3D reconstruction strategy was tested on the Mittweida water tower and its close surroundings. The tower is 38 m high and consists of two sections with varying widths of about 10 and 16 m. Featuring large dimensions, small details and free space in its surroundings, it poses a suitable object to test reconstruction capabilities in combination with varying camera-object geometries, camera settings and image resolutions. In Figure 3A, a model of the tower and its surrounding area is shown. Here, the drone was programmed to fly a circle with 50 m radius at an altitude of 50 m above ground level. Images were extracted from recorded HD video material every single second, resulting to 111 images, and processed as proposed. Although major details are discernible, smaller features with a size of about less than one meter are difficult to identify. On a standard desktop machine (eight 3.5 GHz CPUs, 32 GB RAM, GeForce 750 GTX Titan), the 3D reconstruction process required about 1.5 to 2 hours of computation time and 1.5 GB of disk space. Hence, with this set-up, obtained models are only suitable for fast mapping of larger areas. Interestingly, a model computed from only 28 images (four seconds per image) shows only minor discrepancies in quality compared to the model computed from 111 images. Said model is shown in Figure 3B. In addition, computation time for this model is only 20 minutes.

In the reconstruction process of the tower basis the drone was programmed to fly at three meters above ground level with a distance of ten meters from the tower. The obtained model is shown in

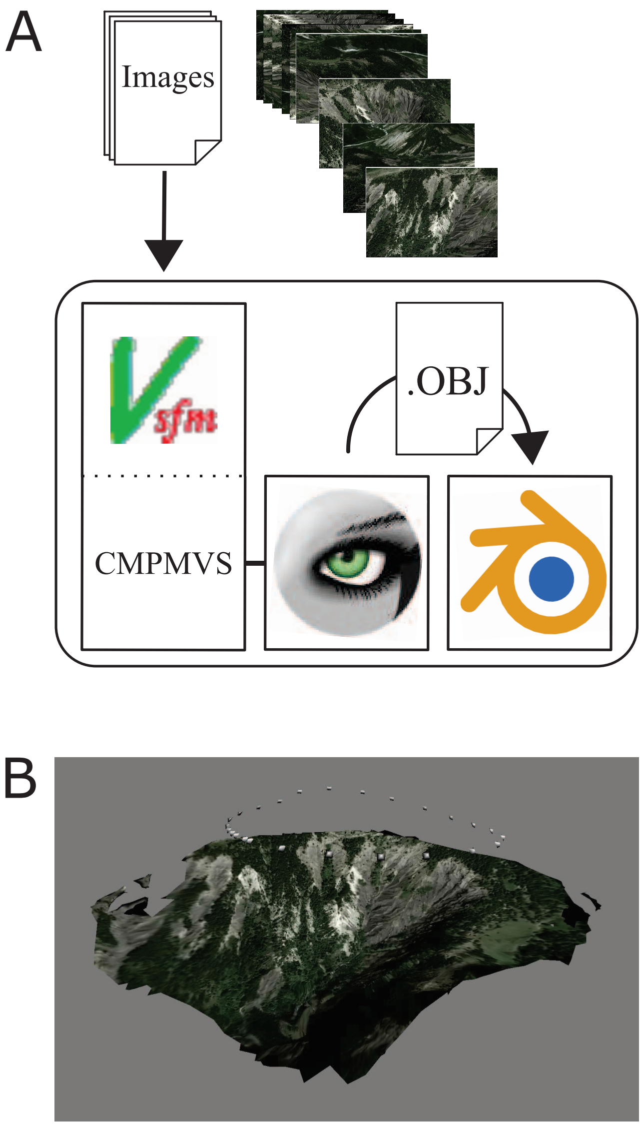

Figure 1. A: Schematic workflow of the proposed 3D disaster site reconstruction strategy using aerial images by means of open source software. Obtained images are input to VisualSFM [7], whereas 3D points for initial object/area reconstruction are computed. CMPMVS [10] is utilized next for point enrichment and mesh construction which is eventually refined or merged with other meshes using MeshLab [11]. Blender [12] is utilized for further refinement and post-processing. Best reconstruction results are obtained if images are recorded on a circular flight path around the object/area of interest. B: 3D model reconstructed from pseudo-aerial images of Flight 4U9525 crash site retrieved from Google Earth [14]. White dots indicate virtual camera locations computed by VisualSFM.

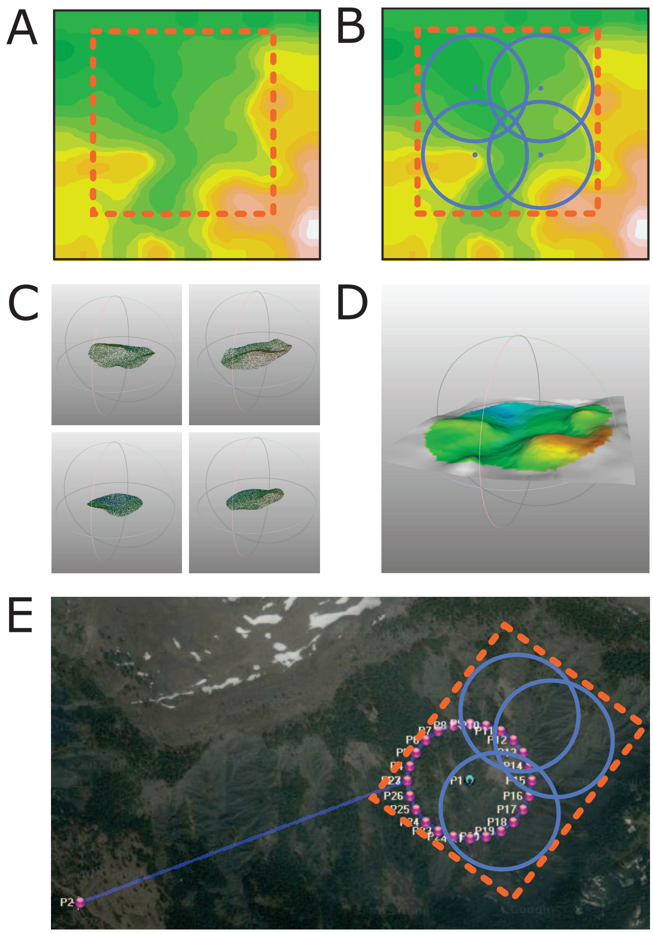

Figure 2. 3D reconstruction strategy for extensive disaster sites. A and B: 3D-reconstruction of a large disaster site is realized by merging computed meshes obtained from image sequences of shorter circular flights covering the entire area. C and D: Overlapping flight paths ensure proper mesh alignment and unification. E: Screen capture of a planned circular flight in MikroKopter-Tool V2.12a shown for the Flight 4U9525 crash site [14] as the region of interest. Throughout the flight, the camera is pointed towards the point of interest (P1). Three additional overlapping circular flights (indicated by blue circles) are required to reconstruct the area based on obtained image sequences.

Figure 3C. Here, sixty 24 megapixel images were recorded at an angular offset of 6° using interval triggering. Time and disk space demands are significantly larger for this set-up (6.5-8 hours, 53 GB disk space). Computational demands are accompanied with a high degree in object and surface detail, even for small objects ($<$ 10 cm), suitable for detailed reconstruction and mapping of smaller areas.

In summary, camera-object geometry, image resolution and the number of considered images has to be chosen in accordance to the features of the target object/area and the problem to address. Especially computational time demands have to be taken into account during flight planing.

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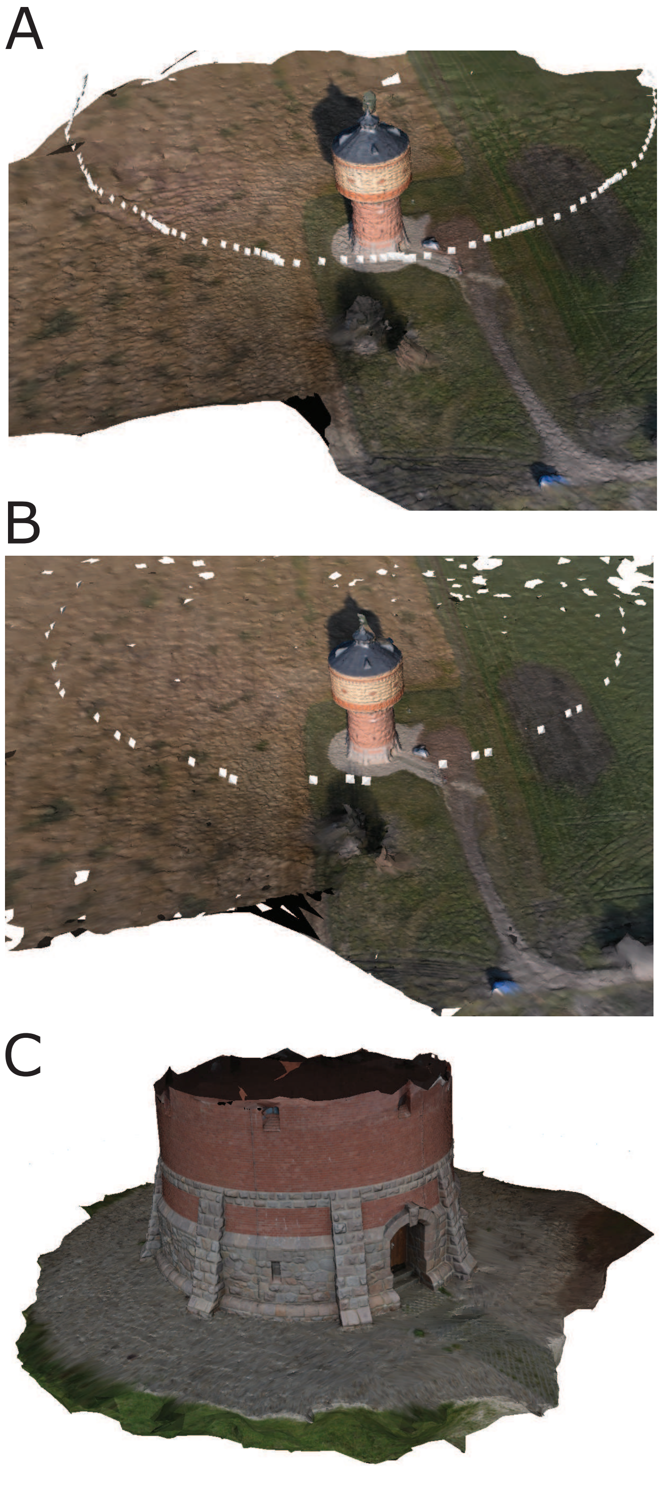

Figure 3. A and B: 3D model of the Mittweida water tower (height: 38 m) obtained from 111 respectively 28 images extracted from HD video. C: 3D model of the tower basis (width: 10 m) generated from sixty 24 megapixel images.

IV. Conclusion and Future Work

Fast reconstruction of disaster sites can be of great value in disaster response and recovery. The presented work is focused on the conceptual design of such a 3D disaster site reconstruction strategy by means of open-source software based on aerial images obtained by drones. Models generated from images obtained during flight show that model quality is greatly dependent on camera-to-POI geometry and image resolution. It is further pointed out that even the resolution of images extracted from high definition video is not always sufficient for detailed disaster scene reconstruction. Although lower image resolutions lead to coarse models, time demands for automated model calculation are relatively small and obtained level of detail can be sufficient for fast mapping processes, which makes these models adequate for the exploration of large disaster sites and providing support to the rescue forces in response planning. High resolution models are achieved by using high resolution images (e. g., 24 megapixels), whereas computational demands increase significantly.

Future work requires the recording of more aerial drone-based images and evaluation of generated meshes, whereas the conceptual strengths and weaknesses are ought to be identified and verified. Here, the focus lies on the quantification of reconstruction error. Furthermore, specialized payloads such as thermal imaging systems shall be considered in the future.

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