Incrementally Generated Wide Area Mosaics for Rescue Scenarios by Networked UAVs

Daniel Wischounig-Strucl and Bernhard Rinner

Networked and Embedded Systems, Alpen-Adria-Universitaet Klagenfurt,
Klagenfurt, Austria
{daniel.wischounig-strucl,bernhard.rinner}@aau.at
http://www.cdrones.com, http://www.pervasive.aau.at

Abstract. Unmanned aerial vehicles (UAVs) are an emerging research area. We equip them with high resolution cameras and build a wireless network for wide area surveillance. The sensed data is processed on-board and transmitted over the wireless network to generate an orthographic mosaic.
In this work we present an image transmission scheduling and incremental mosaicking approach. Our experiments with up to four UAVs demonstrate very short delays for the final mosaic, due to the prioritization of image resolution levels and the incremental mosaicking starting from low resolution unconnected images.

Keywords: micro UAV, mosaic, incremental, online, disaster, bundle adjustment

1 Introduction and Related Work

In various applications for wide area surveillance of inaccessible areas, such as disaster scenarios where no pre-installed infrastructure is available, unmanned aerial vehicle (UAV) systems present growing relevance for frequent and continuous monitoring. A very short launch phase and processing time for the output is of outermost importance. Hence, expensive methods are not acceptable. Considering the given requirements, i.e., quick output response, low flight altitude, among others, our mobile camera network is built from UAVs that are able to place themselves autonomously forming a wireless network to transmit sensed data, i.e., high resolution images, position and orientation data, cf. [1]. In this work we present a UAV system with embedded processing capabilities and utilizing a wireless network to transmit images and mosaick an overview image.

We propose an UAV system implementing a custom network scheduling that prioritizes images and meta data to utilize the limited communication channel efficiently. Furthermore, the online generation of the overview image is executed distributed on the camera nodes and incrementally on the ground station exploiting intermediate delivered results. During mission execution, processing results are used to provide feedback to the UAV's control to allow active interventions on certain events, such as the absence of area coverage or bad image quality.

Wireless camera networks on mobile platforms for disaster response introduce additional challenges in terms of bandwidth scheduling and resource planning. In [2] wireless sensor networks built from off-the-shelf cameras are able to ubiquitously retrieve video and still images, among other sensor data, from the environment. In [3] UAVs use two separated network architectures for control data and sensor data communication. The overview mosaic is built offline and with human interaction.

The dynamic placement, wide area coverage and the network communication play central roles in our project, while various UAVs projects, cf. [4–6], dispose offline processing with expensive global optimization methods to achieve an appealing mosaic. In addition to the online aerial mosaic generation proposed by [7] we employ an incremental multi-stage refinement process.

2 UAV System Description

In our use case of wide area surveillance for disaster scenarios the available resources are very limited. The majority of human resources is required for other tasks instead of operating the UAVs, as well infrastructural resources, such as communications, are rarely available. Hence, our proposed wide area surveillance system works as unsupervised and autonomous as possible. Autonomous operation allows the handling of multiple UAVs, from take-off to landing, with a minimum of expertise and training of operators required.

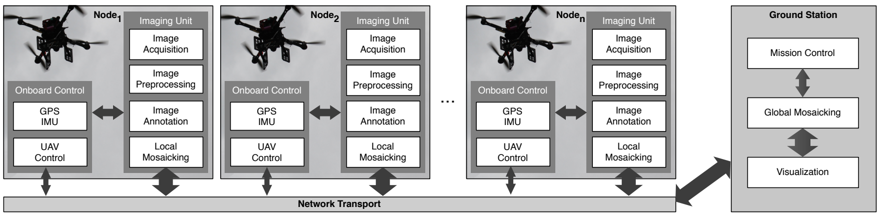

Fig. 1. System overview presenting multiple UAVs with their processing components and the common communication layer.

Our proposed system for monitoring unknown wide areas compromises three main components presented in Fig. 1:

Mobile Camera Nodes (UAVs): Each of the aerial camera nodes consist of the UAV, sensors such as a high resolution camera, GPS and IMU sensors, and two processing units, i) the *Onboard Control* unit for flight navigation, ii) a mid-performance embedded processing unit as *Imaging Unit*

Network: A wireless network infrastructure is deployed for transmitting captured images and sensed meta data. Our proposed custom application layer protocol schedules the transmission of captured data whereas it does not rely on any specific transport protocol.

Ground Station: Single images of different resolutions are merged to an overview image according to the preprocessed mosaicking data and incrementally refined by additional received data. The result is presented to the operator and frequently updated.

3 Distributed Image Acquisition and Processing

To allow an efficient mosaicking on the limited resources on the UAV the process is split into acquisition, preprocessing and local mosaicking. Besides, the global mosaicking is executed on the ground station comprising the combination of all single mosaics and images to an overview mosaic.

Due to limits of the available network bandwidth and wireless network connectivity in the whole area, a complete transmission of high resolution images may typically not be completed during flight time. Consequently, the mosaicking is started with a rough placement of low resolution images by metadata only and enhanced by higher resolution image data and structure data later. At the ground station we employ such a hybrid mosaicking approach incorporating multiple mobile camera nodes as proposed in our previous work [8].

Image Acquisition and Transmission

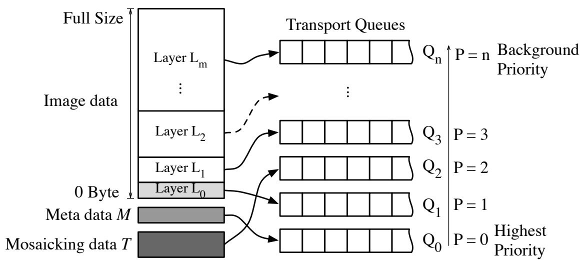

Fig. 2. Resolution layers of one full size image are presented in the bit stream view. The annotated metadata M, image layer L_0 and mosaicking data T is enqueued to the transportation queues with the highest priorities.

When the UAV approaches the target coordinates, for capturing an image, it decreases its speed to reduce the likeliness of motion blur. Each captured image is annotated with metadata from the onboard control, e.g., GPS and IMU data, and preprocessed for transmission. Due to the high resolution camera full sized images are too large to be transmitted directly. Hence, on the UAV images are encoded with progressive JPEG2000 to gain different resolution and quality representations within one stream without additional overhead. A defined number of layers in resolution-layer-component-position (RLCP) mode, cf. Fig. 2, are accomplished by the encoding process, annotated with different priorities and enqueued for transmission accordingly. The lowest quality and resolution layer and the metadata is enqueued with the highest priority for transmission.

Prioritized Data Scheduling

Our network protocol, cf. [9], conducts $n = m+2$ transport queues with different priorities managed on the UAV, whereas m is the number of image resolution layers. For every new image the metadata M is enqueued to the highest priority queue Q_0, cf. Fig. 2, while image layers are enqueued for transmission according to their resolution. Fig. 3 depicts the transmission of the individual data chunks

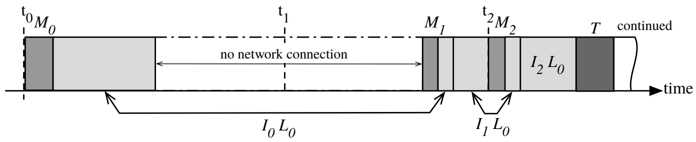

Fig. 3. The metadata packages and image data are shown as received at the ground station from the camera node. In situations of bad network connectivity the data transfer gets stalled, as presented in this example.

according to our proposed scheduling scheme in case of missing network connectivity. The first image is taken at t_0 and the corresponding metadata M_0 is transmitted with the highest priority $P = 0$, followed by the lowest resolution and quality layer I_0L_0 with a lower priority $P = 1$. At t_1 the next image I_1 is captured and the metadata M_1 interrupts the lower prioritized queue Q_1. After the processing of at least two images on the imaging unit the computed mosaicking data T, i.e., image transformations, camera poses, and selected structure data, are transmitted with the priority level $P = 2$ subsequently after the image layer L_0.

Incremental Mosaicking

The initial mosaic, by the simple projections on the ground plane according the meta data and camera extrinsics is incrementally refined when more images are considered. By conducting bundle adjustment, cf. [10] for computation of the scene structure and camera extrinsics the mosaicking is improved. Furthermore single and non-overlapping images are presented in the overall mosaic only by their metadata projection. For effectiveness overlapping images are pre-determined based on a rough projection estimated from GPS and IMU data, before applying the keypoint matching among them. In Fig. 4 such mosaics is

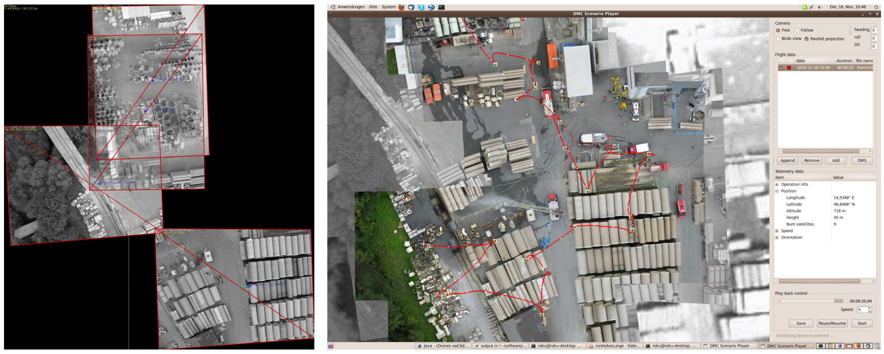

Fig. 4. A rough mosaic from data of multiple UAVs, placed by metadata only (left). The final mosaic after two complete flight rounds overlaid onto Google Maps, with blending executed and visualized to the operators (right).

presented immediately to the operators, where images are blended with subjacent images according to the methods presented in [11] and [12] for an appealing representation.

4 Results and Conclusion

In this work we have shown an incremental mosaicking approach for wide area monitoring with scheduled data transmission. Immediate presentation to operators can be achieved due to the prioritized data scheduling over the wireless network when transmitting the pre-processed data to mosaic the overview images on the ground station. The average flight time of one UAV is less than 15 minutes, and it is taking about 40 to 60 images depending on the planned route. In one test, the first overview is received and visualized after a few seconds, when four images (of resolution level L_0) are received as shown in Fig. 4 (left). After 192 seconds, in total 12 images and image transformations are received to generate the overview mosaic, but with reduced resolutions. While after 960 seconds the whole area is already presented in Fig. 4 (right), in the operator's console, and is increased by additional images and higher resolutions to the end of the mission.

Furthermore, in this work we have evaluated that our image transfer scheduling outperforms the continuous transmission of fixed sized images over the wireless network and is able to utilize the available bandwidth is optimally. Low resolution representations of all participating UAVs are transmitted with an acceptable delay and presented immediately. The distributed mosaicking process could further be improved by dynamically arranging tasks and resources among participating UAVs to exchange mosaicking data and enhance the local mosaicking.

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