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UAV path planning method for digital terrain model reconstruction – A debris fan example

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ABSTRACT

This research develops an unmanned aerial vehicle (UAV) path-planning method that aims to ensure the required image overlap and optimize the flying routes when applying the UAV for digital terrain model's (DTM) reconstruction. To collect images on a terrain for image modeling, enough overlap between each collected image must be ensured. In addition, when planning the optimized flying routes for collecting images on a debris fan, the specifications of the debris fan and the limitations of the UAV should both be taken into consideration. The path planning method takes a debris fan as an example and refers to the specifications of a debris fan and the limitations of the UAV. The developed method can help the operators to ensure the image overlap through dividing the debris fan into cells by the UAV's maximum image collection distance interval. The near-optimized UAV flying paths are calculated though applying a modified ant colony optimization algorithm (ACO). The developed method is validated to be able to help operators to sufficiently use the limited UAV batteries and evaluate the efficiency of the image collection process. A site experiment was also conducted for validating the workability of the developed method. The result of the comparison shows that the path-planning method can reduce 18.5% of the image collection time. It also confirms that applying the method on an actual debris fan can guarantee the required image overlapping and generate a complete DTM without model breaking.

1. Introduction

Debris fans usually have serious sediment deposition problems. It may lead to damming of the trunk river and reduction in its capacity, probably causing flooding of resorts downstream. Constructing a digital terrain model (DTM) of a debris fan can help the surveyor to monitor the debris fan's sediment deposition situation year by year. For the construction of the DTM, data collection is a critical step, which influences the feasibility, efficiency, and accuracy of the entire model generating process. Human survey using a total station is a traditional approach to survey a terrain. However, manual survey is not only time consuming but also a labor-intensive approach to collect data for DTM construction. Therefore, approaches such as those using Light Detection and Ranging (LIDAR), satellite images, or unmanned aerial vehicles (UAVs) with the image modeling technique have been developed.

Recently, applying a UAV system with an image modeling technique for DTM reconstruction has become a trend due to the UAV's low cost and high flexibility. The UAV system allows people to collect data remotely from inaccessible areas and protect them from dangerous environments simultaneously. Although using a UAV system is a convenient and efficient method for DTM reconstruction, the following issues need to be solved when applying such techniques for debris fan DTM reconstruction. The first issue is how to obtain images with enough overlap for model generation. During image modeling, sufficient overlap of each image is very important, without which the model may break. The entire process of model generation is time consuming and is always performed in a lab and not at the site. Therefore, a path-planning method must ensure that the collected images have enough overlap with each other. Second, the flying routes of the UAV should be optimized considering the limitation of batteries. When collecting image data from a debris fan, recharging of the batteries may contribute to unnecessary waiting time. Therefore, it is important to find an optimized flying route with limited battery consumption.

The objective of this research is to develop a path-planning method for UAV for debris fans' DTM reconstruction. Although many path-planning tools for UAV have been developed recently, they are insufficient in handling the photogrammetric surveying applications on a debris fan. This research proposed a UAV planning method for debris fan's DTM reconstruction that ensures the required image overlap coverage and finds a near-optimal flying route. By applying this

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method, the accuracy of the collected images can be confirmed and the efficiency of the process can be evaluated.

2. Literature review

DTM reconstruction is considered a critical approach for surveying and monitoring debris fans. The high vulnerability of debris fans makes it worthwhile to construct a DTM for surveying and monitoring. Applying UAV technologies and image modeling for DTM reconstruction has started to become a trend in the past four years. However, no UAV path planning tools have yet been designed for debris fan image collection. When planning the UAV flying path for collecting the images of a debris fan, both the specifications of the debris fan and the limitations of the UAV should be taken into consideration. The following Literature review sections will sequentially describe the specifications of a debris fan and the UAV path-planning method for DTM reconstruction.

2.1. Specifications of debris fans

A debris fan usually has a serious sediment deposition problem because it is located at a relatively gentle section of a rapidly flowing stream or river [1]. Debris flows often dam the channel and reduce its capacity. It may also reduce the river's ability to transport the debris downstream [2]. A debris fan usually causes serious damage when it occurs to disaster like earthquake, heavy rain, or typhoon. Capart in 2010 [3] indicated that the largest debris fan developed during 2007 Typhoon Morakot in the Pu-tun-pu-nas river, located in the south of Taiwan; it dammed the trunk river and caused flooding up to 2 km upstream from the fan during 2007 Typhoon Sepat, which occurred one month later. A debris fan sometimes leads to the formation of dammed lakes, which may cause flooding and damage to the resorts downstream if the dammed lakes are breached [4].

The high vulnerability of a debris fan makes its survey and monitoring for disaster prevention worthwhile; however, some specifications of debris fans, especially large-scaled debris fans, render surveying of debris fans difficult. For example, since a debris fan is always located in the middle of a river, it can be surveyed only in the dry period. The large target area also makes it difficult to conduct the fieldwork. In addition, if the debris fan is located in a mountainous area, the problem of accessibility to the target area becomes another critical issue. Those specifications of debris fans make the traditional field survey labor intensive and time consuming [5]. Therefore, many studies have attempted to solve these problems. For instance, the ground remote sensing techniques were widely used on the geomorphological analysis of surface composition and morphology [6–8]. However, using remote sensing techniques to quantify the characteristics and differences between multiple fan surfaces would be difficult due to its low spatial resolution [9]. Therefore, photography techniques such as aerial photography [10] and satellite images [7] were utilized to survey debris fans. Although using remotely-sensed data and photography could solve the problem of accessibility and evaluate the monitoring efficiency, such technologies could just complement fieldwork instead of replacing it [7].

2.2. UAV path planning for DTM reconstruction

Although UAV can be used in debris fan image collection, there are no existing path-planning tools to guarantee the quality of the collected images. By following the photogrammetric workflow, 3D results such as DTM, contours, textures, and 3D models can be produced on large areas [11]. Niethamer et al. utilized a low-cost UAV to obtain terrain images for the investigation of landslides [12]. Cho et al. tried to use UAV photography to construct DTM for a nonmetal open-pit mine [13]. Roca et al. used UAV with Kinect sensor to collect point clouds of buildings for outdoor building facade inspection [14].

In the past, UAV systems were normally developed for military purpose. The path planning of UAVs focused on fitting the dynamically changing war environments, minimum risk, and maximum efficiency [15]. For instance, Zheng et al. (2003) presented an evolutionary path-planning algorithm for UAVs applied in the battlefield [16]. According to their research, the UAV was able to find a near-optimal route in the battlefield, which could be re-computed immediately for fitting the constantly changing war environments.

As UAV technology advances, the UAV systems are applied in various domains. The path-planning algorithms for UAV systems have been developed in many studies. Sinopoli et al. (2001) developed a computer vision-based navigation system for UAVs to fly from an initial position to a final point in a 3D environment [17]. The navigation system they developed could avoid obstacles and minimize route length. Conte and Doherty (2009) proposed a vision-based navigation system for a remotely controlled helicopter. They combined the inertial sensors, visual odometry, and geo-referenced aerial images for the navigation system [18]. Weiss et al. (2011) presented a method to reconstruct in real-time textured 3D mesh maps out of a sparse point cloud for a Micro Aerial Vehicle (MAV) to explore in a terrain without obstacle collisions [19]. The path planning method for multiple solar-powered UAVs target tracking in urban environment was studied by Wu et al. They improved the grasshopper optimization algorithm (GOA), called adaptive grasshopper optimization algorithm (AGOA), for solving the solar-powered UAVs cooperative target tracking in urban environment [20]. As for the solar-powered UAVs flying in urban environment, Wu et al. proposed a path planning framework in 2018. A modified interfered fluid dynamical system, called RIFDS, and improved whale optimization algorithm, called IWOA, were utilized for the solar-powered UAVs to calculate the flying path with the avoidance of both sunlight occlusions and building obstacles [21]. Moreover, studies [22–24] have been conducted to design the path-planning algorithm for UAVs to fly through uncertain environments.

In path planning for a UAV used to collect images for DTM reconstruction, sufficient overlap between images must be maintained, a lack of which may lead to the breaking of the model. Siebert and Teizer (2014) indicated that commercially available flight route planning tools cannot effectively handle photogrammetric surveying applications [25]. Therefore, they redesigned the commercial planning tool, Mikrokopter Flight Planning Tool (MK FPT), for photogrammetric survey by guaranteeing appropriate overlapping imagery coverage by inputting specific parameters such as camera specifications and required overlap ratio.

However, collecting images of debris fans is different from other terrains. First, since debris fans are often located in mountainous areas, the limitation of UAV power, usually batteries, should be considered while path planning. Often, it requires more than one trip to finish image collection of a debris fan, especially a large-scale one. Therefore, the path-planning method should sufficiently utilize the limited batteries in each trip. Second, commercial path-planning tools often do not take the take-off and landing positions into consideration. A debris fan is formed in the middle of a river or a stream, which makes it impossible for the UAV to take off in the middle of the target area. The surveyor needs to take off the UAV at the borderline of the debris fan; therefore, the time of flying from the take-off position to the target area and back to the landing position should be calculated when generating an optimized path.

2.3. Related works

From a two-year preliminary research during 2014 to 2016 [29–31], the challenges of applying UAV for debris fan's image collection for DTM reconstruction were found. Through conducting two site experiments on Pu-tun-pu-nas debris fan, the workflow for utilizing UAV on debris fan was defined, and two common UAV flying types were compared. According to the experience of conducting two site experiments