Response to EC1 again:

Authors: Thank you for consideration of our paper. The respond to your comment is as flowing:

Dear Authors, considering the comments received from the reviewers, I ask you to revise the manuscript according to their comments. Please upload a revised version of the paper, with detailed answers to the reviewers' comments. Please try to complete the work in three weeks time.

Authors: Now, we have revised our manuscript according to the comments received from the reviewers, at the same time, a point-by-point reply to the comments and a marked-up manuscript version showing the changes had been uploaded.

Besides point-by-point revise according to the comments of reviewers, another main changes include as follows:

1. We **changed the title** "**Method and application of using unmanned aerial vehicle for emergency investigation of single geo-hazard**" to "**A method for using unmanned aerial vehicles for emergency investigation of single geo-hazards and sample applications of this method**", may be more suitable.
2. We **invited native English speaker conversant with photogrammetric terminology, to help us improve the English writing of the revised paper.**
3. We **checked, modified, and improved all figures and tables.**

We would like to express our great appreciation to you and reviewers for comments on our paper. Looking forward to hearing from you.

Response to RC1 again:

Authors: Thank you for your interests about our paper and valuable comments to improve it. The responds to your comments are as flowing:

GENERAL COMMENTS The paper describes a drone specifically design by the authors for emergency investigations. This UAV was been applied in 3 practical cases to demonstrate its efficacy. In my opinion, there are 3 limits in this paper:

1. The paper contains no mentions of Direct Photogrammetry (DF) approach, but in a drone specifically designed for emergencies and rapid mapping, this approach has to be applied. I suggest the use of DP techniques to measure directly in field external orientation parameters and the application of a post processing BBA to refine the external orientation parameters directly measured. Could this UAV be equipped with sensors for DF? In the case of affirmative answer, I suggest to the authors to include some details of this solution (kind of IMU/GNSS sensors, real time or post processing, used software tools,

and so on);

Authors: Thank you for commenting and suggesting about the DF. Actually, although the DF is not mentioned in the paper, this approach is used, especially in the site investigation and the site fast processing. Specifically, when the GNSS signal can be used during the site investigation, the location information will be automatically wrote into the captured photos, to ensure that the use of fast SfM processing method can generate coarse-precision results with a real space coordinate system in the site fast processing step, please see lines 269-282. If there is no GNSS signal, the layout and measurement of GCPs is indispensable to support the SfM photogrammetric processing, i.e., introducing GCPs to ensure generate results with a real space coordinate system, please see lines 243-246, 299-308. According to the suggestion, the details of DP, including IMU/GNSS sensors (lines 270-282), post processing (lines 299-308), used software tools (lines 277-280, 304-306, 407-409) had been added to the revised paper.

2. Paper don’t describe innovative approach to SfM survey using UAV: merely, there are some details of practical suggestions for UAV survey and some reports of applicative examples, actually known in scientific literature. To complete these descriptions, I suggest to complete the practical details including, in Paragraphs 5.1, 5.2 and 5.3, some information on number of acquired image, flight plan, time spent for the acquisition and post processing, number of points of dense point clouds, density of point cloud, obtained accuracy.

Authors: Thank you for the suggestion. These detailed information had been added in the revised paper, please see lines 424-438, 463-480, 497-506.

3. The references don’t include some important papers on the use of UAV for mapping, environmental application, rapid mapping and emergency investigation. For examples, I suggest: http://link.springer.com/article/10.1007/s12518-014-0144-x
http://www.mdpi.com/1424-8220/15/7/15717 http://www.mdpi.com/2072-4292/8/9/779
http://www.tandfonline.com/doi/pdf/10.1080/19475705.2016.1225229

Authors: Thank you for the suggestion. These references had been carefully read and added to the appropriate location in the revised paper, please see lines 45-57.

Detailed corrections: - Rows 110, 172, 179, 183, 220, 223, 246, 290, 301, 381, 384, 396, 411, 433, 467 Replace GPS with GNSS - Row 320 Replace facade in façade

Authors: Thank you for the corrections. These comments had been reflected in the revised paper.

In addition, three main changes include as follows:

4. We **changed the title** “**Method and application of using unmanned aerial vehicle for emergency investigation of single geo-hazard**” to “**A method for using unmanned aerial vehicles for emergency investigation of single geo-hazards and sample applications of this method**”, may be more suitable.

5. We **invited native English speaker conversant with photogrammetric terminology, to help us improve the English writing of the revised paper.**
6. We **checked, modified, and improved all figures and tables.**

We have tried our best to revise our manuscript according to your valuable comments, and hope that the correction will meet with approval.

Response to RC2 again:

Authors: Thank you for your interests about our paper and valuable comments to improve it. The responds to your comments are as flowing:

GENERAL COMMENTS This paper aims to describe a RPAS and processing pipeline specifically developed for the management of small hazard events. Authors discuss both the platform/sensor technology and the main steps followed during the complete UAV mission workflow. Finally, performance evaluation is carried out on three test cases. Although the core concept is interesting and may represent an interesting issue for the scientific community, several main issues should be addressed by the authors.

1.General remark: the English is very poor and this may prevent a full comprehension of the paper. Photogrammetry-related terminology is vague and often incorrect (e.g. “high-definition photos”, “...for the photos, the definition, scope and overlap rate...”, “planar digital terrain”, etc...). A proofreading by a native English speaker conversant with photogrammetric terminology is strongly required.

Authors: Thank you for the comment. After revised the contents of the paper, we had invited a native English speaker conversant with photogrammetric terminology, to help us improve the English writing of the revised paper.

2.The scientific significance and novelty of the paper should be proved. Which are the advantages of the developed platform/sensor/pipeline compared to other commercial or in-house developed systems? The literature review addresses only general concepts and does not show the novelty and advantages of the newly developed system.

Authors: Thank you for the comment about the scientific significance and novelty of the paper. In fact, The main aim of this paper is to conclude and establish a complete method of using UAV for emergency investigation of small hazard events. In the revised paper, we had strengthened the literature review about this aspect, please see lines 45-63, 70-79.

3.The application field is vague. Authors say that the RPAS is developed for emergency investigation of “single” geo-hazards. What do you mean with the term “single”? If it refers to a limited spatial extension of the natural hazard, this should be better clarify and a clear idea of the intended area size should be given.

Authors: Thank you very much for the comment and suggestion. Indeed, the “single” geo-hazard refers to a limited spatial extension of a natural hazard, so we add a better clarify and a clear idea of the intended area size in the revised paper, please see lines 61-63.

4.No accuracy figures are given. Authors generally refer to “meter-level error” or “centimeter- even millimeter- level accuracy”. How did you evaluate accuracy? Did you adopt Control Points to check the accuracy of orientation results? Did you evaluate the accuracy of the final product? Although accuracy is not the main aim of rapid mapping, a metric evaluation of the methodology is necessary to confirm and support the conclusions.
Authors: Thank you for the comment about the accuracy. And the accuracy is indeed an important indicator of the availability of results, in our method, the GCPs were used for accuracy assessment, simply, the root-mean-square error (RMSE) of GCPs was used as an important indicator. So, we add the accuracy results in 5. three application examples, please see lines 430-437, 472-477, 502-505.

5.Why is direct geo-referencing not dealt with?

Authors: In fact, the direct geo-referencing is used in our method, especially in the site investigation and the site fast processing. Specifically, when the GNSS signal can be used during the site investigation, the location information will be automatically wrote into the captured photos, to ensure that the use of fast SfM processing method can generate geo-referencing results. If there is no GNSS signal, the GCPs layout and measurement is indispensable to support the SfM photogrammetric processing, i.e., introducing GCPs to ensure generate geo-referencing results. Accordingly, above detailed processing method, such as SfM and so on had been added to the revised paper, please see lines 270-274, 277-282, 300-301, 304-308, 402-409.

6.The experimental part is very poor. No details are given regarding the image dataset (GSD?), the accuracy achieved, the time required. This gives limited support to the conclusion drawn by the authors.

Authors: Thank you for the comment. More practical details including the number of acquired image, time spent for the acquisition and post processing, obtained GSD and accuracy, etc., had been added in the revised paper, please see lines 424-438, 463-480, 497-506.

In addition, We **changed the title “Method and application of using unmanned aerial vehicle for emergency investigation of single geo-hazard” to “A method for using unmanned aerial vehicles for emergency investigation of single geo-hazards and sample applications of this method”,** may be more suitable. Moreover, We **checked, modified, and improved all figures and tables.**

We have tried our best to revise our manuscript according to your valuable comments, and hope that the correction will meet with approval.

~~Method ~~A method ~~and application of~~for using unmanned aerial vehicles for emergency investigation of single geo-hazards and sample applications of this method

Abstract. In recent years, ~~the ~~unmanned aerial vehicles (UAVs) have ~~began to be~~become widely used in ~~the~~ emergency investigations of major natural hazards ~~in ~~over ~~a ~~large areas~~, but less~~; however, UAVs are less commonly employed to investigate~~ for the~~ single geo-hazards. Based on a number of successful ~~practices~~ investigations in the Three Gorges ~~Reservoir Area~~Reservoir area, China, a complete UAV-based method for performing emergency investigation~~ methods~~ of single geo-hazards is ~~concluded~~described. ~~Firstly, ~~First, a customized UAV system ~~consisting ~~that consists of a multi-rotor UAV subsystem, an aerial photography subsystem, a ground control subsystem and a ground surveillance subsystem is described in detail. ~~Then, t~~The implementation process, which includes four steps, i.e., indoor preparation, site investigation, ~~site fast processing~~on-site fast processing and ~~applying~~application, and indoor comprehensive ~~processing and applying~~processing and application, is then elaborated, and two investigation schemes~~ including~~, automatic and manual, that are used in the site investigation step are put forward. Moreover, some key techniques and methods, e.g., the layout and measurement of ground control~~s~~ points (GCPs)~~ layout and measurement~~, ~~the ~~route planning, flight control~~the flight~~ and ~~shooting~~image collection~~ process control~~, and the Structure from Motion (SfM) photogrammetry processing, are explained. Finally, three applications are given. ~~Practice show~~Experience has shown~~s~~ that~~,~~ using ~~the ~~UAVs for emergency surveys of single geo-hazards ~~can not only ~~greatly reduces the time, ~~strength ~~intensity and risks ~~of the~~associated with on-site work~~, but also~~ and provides valuable, high-accuracy, high-definition ~~valuable ~~information ~~to well~~that support~~ the~~s emergency ~~treatment~~responses.

Keywords. single geo-hazard; landslide; emergency investigation; unmanned aerial vehicle (UAV); ~~emergency treatment~~emergency response

1 Introduction

The aim of the emergency investigation of geo-hazards is to provide basic and essential information, including ~~disaster characteristics~~the characteristics of disasters, damages~~loss situations~~ and environmental conditions~~, etc.~~, for use in emergency decision-making and effective ~~treatment~~response~~, so~~. These investigations are~~ it~~ ~~is~~ therefore a top priority,~~,~~ and ~~needs to emphasize ~~the speed and efficiency of the implementation process~~,~~ and the accuracy of the results must be further improved (Liu, 2006; Liu et al., 2010; Lu and Xu, 2014). In general, ~~the~~ traditional methods of emergency investigation ~~for ~~of geo-hazards ~~is ~~are used~~,~~; i.e., ~~the ~~specialists ~~go around and ~~inspect ~~on ~~the ~~disaster body~~affected area with cameras and simple measurement tools, then ~~conclude ~~report their conclusions~~information~~ based on the field investigation and professional knowledge. There is no doubt that these efforts ~~in ~~using the traditional method require ~~more ~~substantial manpower, long~~er~~ working hours and

~~greater~~ highly intense work~~ intensity, and~~; moreover, they often face difficulties because~~in~~ ~~the inaccessibility of humans to~~ certain ~~areas~~ parts of ~~the~~ geo-hazards, such as high cliffs or areas covered by lush vegetation~~ covered~~, are inaccessible to humans. In particular, ~~these~~ on-site investigators ~~have to take the great~~must contend with the considerable risks ~~of further~~associated with additional disasters that may occur during the process of the emergency investigation. In addition, the conclusions of these investigations are often inaccurate~~,~~ because they are ~~mostl~~primarily~~y~~ local, qualitative ~~or~~ and speculative~~-based, e~~. Even some quantitative results, such as the length, width, or area of a geo-hazard, may ~~have a large deviation~~deviate strongly from the actual situation. Therefore, relying solely on ~~the~~ traditional ground-based emergency investigation methods ~~would~~ inevitably reduces the efficiency and effectiveness ~~for~~ of ~~the geo-hazard emergency~~ decision-making and the ~~treatment~~responses associated with geo-hazard emergencies.

Remote sensing of features ~~in~~ is fast and~~,~~ ~~macroscopic,~~covers large areas at high resolution, and it has ~~the irreplaceable~~considerable advantages in the field~~s~~ of emergency investigation of major natural hazards (Joyce et al., 2009; Boccardo and Tonolo, 2015). Along with the rapid development of unmanned aerial vehicle (UAV) remote sensing technology, it has been widely used in mapping (Aicardi et al., 2015), environmental investigation (Aicardi et al., 2016) and emergency investigation (Boccardo et al., 2015)~~, especially~~. Remote sensing from UAVs has been especially widely used in the emergency investigation of geo-hazards ~~emergency investigation for some~~given its unique advantages, such as low cost, eas~~y manipulation~~e of operation, ~~less~~ minimal risk and efficient image acquisition~~, etc.~~ (Lewis, 2007; Adams et al., 2014; Li et al., 2014; Fernandez Galarreta et al., 2015). For example, in the USA, ~~the~~ UAVs were used ~~for~~ to perform damage inspections after ~~the~~ Hurricane Katrina (Pratt et al., 2006) and Hurricanes Wilma and Ike (Steimle et al., 2009~~);~~). ~~in~~ In Taiwan, a helicopter UAV was used to collect imagery to support post-disaster reconnaissance, disaster restoration and reconstruction assessments after ~~the~~ Typhoon Morakot (Chou et al., 2010)~~; i~~. In addition, ~~the~~ UAVs have gradually become ~~the~~ an indispensable mean~~ for~~s of disaster investigation and assessment after earthquakes, ~~e.g.~~ e.g., the Wenchuan earthquake in 2008 (Zhou et al., 2008), the L’Aquila earthquake in 2009 (Quaritsch et al., 2010), the Haiti earthquake in 2010 (Huber, 2010), the Japan earthquake in 2011 (Ackerman, 2011), and the Lushan earthquake in 2013 (Xu et al., 2014)~~, etc~~. However, the above applications show that ~~the UAVs~~UAVs are mainly used in ~~the~~ emergency investigations or ~~the~~ loss assessment~~ of~~s associated with major natural hazards, e.g., earthquakes or ~~the~~ their secondary geo-hazards~~, e.g.,~~ (landslides and rock collapses) ~~in a~~that cover large area~~ caused by major natural hazards~~s. These UAV systems are usually large, complex and costly, and the acquisition of the final results ~~also requires~~is a very involved ~~professional~~ process~~ with a~~ that requires~~ long~~ large amounts of time. ~~Actually~~Moreover, ~~in the annual occurrence of a~~of the large number of geo-hazards that occur annually, ~~the~~ “single” disasters with limited spatial ~~extension~~ extents (such disasters usually ~~with~~ have an area that extends from a few hundred to several million square~~ meter~~ metres) and limited volumes (which usually extend from a few thousand to tens of millions of cubic~~ meter~~ metres) account~~ed~~ for the vast majority~~, e.g.,~~. For example, in 2015, a total of 8,224 geo-hazards (~~landslides accounted for the vast majority~~of which most were landslides) occurred in the mainland area of China~~, of which~~. Of these events, 8,180 were medium- (0.1-1.0 million m^3) and small-~~ -~~(less than 0.1 million m^3) sized~~, accounting~~. These events accounted for 99.5% of the total number of events, and the direct economic losses from these events were 200 million USD, ~~accounting~~ which represents~~for~~ 55.8% of the total direct losses (Mlr P.R. China, 2015).~~ It can be seen,~~ O~~o~~n the one hand, it can be seen that the emergency investigation ~~and treatment~~ of single geo-hazards and the response to such events is very necessary for the prevention and mitigation of disasters~~ prevention and mitigation, o~~. On the other hand, because of the potentially greater losses and huge amounts, ~~it usually requires more~~ efficient and effective methods are typically required;~~,~~ e.g., only a few days or even hours ~~to be given~~are usually available to propose the ~~treatment~~ response measures. In this case, ~~more~~ a simple, flexible and small~~-sized~~ UAV system, as well as a ~~more quick~~rapid, efficient on-site image acquisition method and UAV-based remote sensing results processing method ~~had to~~must be used~~,~~ to ensure that ~~in the shortest possible time to complete~~ the whole airborne-based emergency investigation procedures can be completed in the shortest possible time, thus~~en~~ providing valuable information for ~~the~~ subsequent ~~works~~ efforts, such as ground-based investigation or the design of ~~emergency treatment~~emergency response~~ design~~s. However, ~~there is~~ no complete, systematic and effective method of using UAVs for the investigation of single geo-hazard~~ emergency investigation at~~s presently exists, and many challenges, ~~e.g.,~~such as the lack of customized UAV systems and~~,~~ the lack of ~~a~~ sound on-site implementation ~~process and~~ methods~~, etc.~~, are hampering ~~the~~ the use of UAVs in specific applications.

The main aim of carrying out this study is~~ expected to base on~~ to describe a number of successful ~~practices~~ examples of using UAVs to perform emergency investigation of~~e~~ geo-hazards in the Three Gorges ~~Reservoir Area~~Reservoir area of~~,~~ China~~,~~ in recent years and~~,~~ to ~~conclude and~~ establish a complete method of using UAVs for emergency investigation of single geo-hazards~~, which include the~~. This method includes a customized UAV, the implementation ~~process~~ of UAV-based investigation, the key techniques and methods used during the investigation and the processing of the results~~ processing. And~~. In addition, ~~finally,~~ three applications are ~~given~~ provided to demonstrate the applicability of the proposed method.

2 Customized UAV

Most ~~of the~~ single geo-hazards (which mainly ~~refers to~~include landslides, rock collapses and debris flows) that ~~need to be~~require emergency ~~investigated~~investigation, although they are generally of medium or small size, are often located in mountainous areas with rugged topography, where only a limited ~~range of visible~~area can be observed from the ground~~ view~~, and ~~with~~ that experience changeable meteorological conditions, e.g., uncertain wind ~~power~~ speed and direction. ~~Besides,~~ In addition, they are often located in~~ the~~ traffic arteries or crowded places, such as tourist attractions, where there are usually ~~have~~ many buildings and a variety of public facilities, e.g., telecommunications and power towers and power lines~~, etc.~~, which may ~~revolve around~~surround or cross ~~through~~ the entire~~ disaster body~~ area affected by a given disaster. Therefore, in order to fully adapt to the complex environments in which ~~the~~ geo-hazards may be located, ~~the~~ UAVs used ~~for carrying~~to carry out ~~the~~ emergency investigation should meet some basic requirements, e.g., small size, light weight and~~,~~ quick ~~assembling~~ assembly and ~~disassembling~~disassembly;~~;~~ easy ~~taking~~ takeoff and landing and~~,~~ ~~no~~ a lack of special site requirements; simple, flexible and convenient ~~control of flight~~ flight control and ~~taking photos~~image collection; a stable flight control system and a reliable~~, perfect~~ failure protection function; strong wind resistance and~~,~~ a reliable aerial gimbal system~~s~~ ~~of~~ for carrying the camera; a powerful ground control station and a~~,~~ stable image and data transmission system; and a certain endurance that ~~guaranteeing~~ guarantees that a flight can cover the ~~whole~~ entire area ~~of~~ affected by ~~the~~ most single geo-hazards.

According to the above requirements, combined with the comprehensive considerations of applicability, security, stability and economy (which mainly refers to the low cost of initial construction and later maintenance of the UAV system), a number of on-site tests and practical applications were carried out for ~~the~~ single landslides in the Three Gorges ~~Reservoir Area~~Reservoir area, China~~, and f~~. Finally, a UAV system was customized~~, ~~. A photograph of this system is shown in Fig. 1~~ shows the photo~~, the system architecture and the main function modules are shown in Fig. 2, and the core components and main features of the customized UAV are shown in Table 1.

The customized UAV system consists of four subsystems, including a multi-rotor UAV subsystem, an aerial photography subsystem, a ground control subsystem and a ground surveillance subsystem~~multi-rotor UAV subsystem, aerial photography subsystem, ground control subsystem and ground surveillance subsystem~~, ~~details as follows~~which are described in detail below.~~:~~

~~–~~(1) A customized four-axis and eight-rotor carbon ~~fiber~~ fibre airframe is used. The outstanding advantages of this design include its high strength~~, strong~~ and power and light weight (the whole aircraft with its camera and the aerial gimbal system~~s~~ is less than 5 kg)~~. And~~. In addition, compared with ~~the~~ fixed wing aircraft, it ~~has~~ is smaller~~ size~~, has better ~~maneuverability~~manoeuvrability and ~~more~~ enhanced fixed-point hovering capability~~, i~~. In particular, ~~no~~ special sites for taking off and landing are not required, which is very important for ~~the use of~~using UAVs to quickly investigate ~~the~~ single geo-hazards~~ tha~~, which~~t~~ are usually located in complex environments. Although the ~~endurance~~ battery life is poor~~, i.e., ~~ (it provides approximately 20 minutes of flight time),~~e,~~ if ~~calculated at an usual~~an average flight speed of 5 m/s is considered, the resulting flight distance of ~~about 5~~approximately 5 km ~~can~~ guarantees that one flight is sufficient to cover the whole area of ~~the~~ most single geo-hazards. Even if multiple flights are required, only the battery needs to be replaced.

(2) The flight control system, which directly controls the processes of flight and ~~shooting~~image collection, is the "brain" of the UAV system, and its performance and stability directly determine the functioning and the security of the whole system. ~~Nowadays~~Currently, ~~there are~~ many mature commercial ~~products of~~ flight control systems exist; however,~~, but~~ they are closed-source systems~~, so~~. Thus, in the event of failure, ~~the only thing to do is to~~the unit must be returned to the factory for repair or re-purchased, resulting in high~~ economic and time~~

~~costs~~ costs in money and time. Therefore, a widely used open source flight control system, i.e., Pixhawk 2.4.5 (Meier et al., 2012) that~~ with ~~ has dual processors, is used~~, and its~~. The high robustness and powerful data processing capacity of this unit have been recognized. Equipped with a high-performance Global Navigation Satellite System (GNSS) module, data and image transmission modules, etc., this~~e~~ flight control system ~~can totally~~provides complete support ~~some ~~for several necessary functions, such as route planning, flight positioning, real-time data and image transmission, and so on.

(3) The aerial photography subsystem, which is used ~~for ~~to collect overhead or oblique ~~shooting~~ high-resolution images of ~~the ~~geo-hazards,~~ to~~ serves as the core data source of the emergency investigation information. Thanks ~~for ~~to the rapid development of new digital photogrammetric technologies, especially ~~represented by the ~~Structure from Motion (SfM) photogrammetry (Westoby et al., 2012; Li et al., 2013), which is ~~developed ~~based on computer vision algorithms, the requirements of early aerial photography equipment have been~~is~~ greatly reduced. Therefore, only a Sony HX200 digital camera~~,~~ with 18~~ mega~~ effective megapixels~~,~~ and a Vario Sonnar T* 4.8-144~~4mm~~ mm F/2.8–5.6 lens~~,~~ is used to take the photographs~~. And ~~. In addition, in order to keep the camera ~~stability ~~stable to ensure ~~clear shooting~~the collection of clear images~~,~~ or accurately adjust the lens orientation according to actual needs, a three-axis brushless aerial gimbal system~~s~~ is used to carry the camera. The camera shutter and the aerial gimbal system~~s~~ are entirely ~~all ~~controlled by the flight control system.

(4) The ground control subsystem~~,~~ mainly includes the ground control station, which is a notebook computer equipped with the UAV’s ground control software.~~ To match~~ For compatibility with the Pixhawk flight control system, the corresponding open source ground station software, i.e., Mission Planner 1.3.37 (Team, 2016) is used~~. And ~~. In addition, by interacting with the flight control system, the software can ~~achieve some~~carry out several core functions, including ~~UAV’s ~~the debugging and maintenance of the UAV, ~~parameter settings~~setting parameters, and route planning, monitoring and control~~l, etc., i~~. In a word, ~~by using~~using the ground control station and the flight control system, the whole process of flight and ~~photos shooting~~image collection can be fully automated. In addition, a ~~remote controller~~remote control provides manual control of the flight ~~is used to control the flight by manual way ~~in case of emergency.

(5) The ground surveillance subsystem should be established to display real-time flight images and flight state data~~, which~~. This subsystem provides timely and accurate information ~~for ~~that enables operators to make effective~~ly~~ ~~judgment~~judgements, decisions, and manipulations, to ensure the flight safety. ~~There is a~~In the key on-screen-display (OSD) module, ~~by which ~~the flight state data~~ is~~ are superimposed on the real-time flight images~~. And ~~. In addition, then, all ~~these ~~of this information ~~are ~~is transmitted to the ground terminal monitor ~~by using~~using the image transmission system (including the image delivery module on the aircraft~~,~~ and the image receiving module on the ground terminal monitor).

The customized UAV system (including the Sony HX200 digital camera, but not including the computer ~~which~~that is equipped with the ground control software) ~~only ~~costs only $1825, which is equal to the price of the DJI Phantom 4 pro, a current and very popular consumer-level UAV. ~~But~~ However, the image quality of the Sony HX200 digital camera is clearly better~~, and m~~. Moreover, the customized UAV ~~has~~ displays better ~~power~~ performance and wind resistance. In short, our customized UAV system has carried out more than 20 ~~missions of~~ emergency investigation ~~for~~s of single geo-hazards in the Three Gorges ~~Reservoir Area~~Reservoir area. ~~Besides~~ S~~the s~~atisfactory ~~photos~~photographs of every geo-hazard have~~d~~ been obtained, and there has not been a runaway accident, which ~~fully proved~~ demonstrates that the system has ~~a positive~~substantial applicability, safety and reliability~~, and is~~ and is very suitable for the emergency investigation of single geo-hazards, even in ~~the~~ mountainous environment~~s just~~ like that of the Three Gorges ~~Reservoir Area~~Reservoir area.

3 Implementation process

The implementation process of using a UAV to perform emergency ~~investigate~~ investigations of~~the~~ single geo-hazards can be divided into four steps, i.e., indoor preparation, site investigation, ~~site fast processing~~on-site fast ~~and applying~~processing and application, and indoor comprehensive ~~processing and applying~~processing and application. ~~Fig.3~~Fig. 3 shows this process in detail~~detailed processes~~ and the tasks ~~of~~ involved in ~~every~~ each step, ~~elaborated as follows~~which are described below.

3.1 Indoor preparation

Performing the necessary indoor preparation can improve the efficiency of on-site emergency investigation~~,~~ and mainly includes battery charging, initial inspection of the UAV system ~~initial inspection~~, and preliminary route planning.

3.1.1 Battery charging

At present, our system components ~~are~~ use~~d~~ lithium batter~~y powered~~ies. To protect the efficiency and prolong the service life of ~~all~~ lithium batteries, when they are not ~~used~~in use, the voltage of ~~every~~ the lithium cells should be maintained at 3.8 v or so (Broussely, 2002), that is, neither fully charged nor ~~fully~~ empty. Therefore, ~~fully charge~~charging of~~d~~ all of the lithium batteries ~~of~~ used by every component~~s~~, including the UAV, the camera, the ~~remote controller~~remote control, the notebook computer equipped with the ground control station, and the terminal monito~~r, etc.~~r, is the primary indoor ~~work~~task.

3.1.2 Initial inspection of the UAV system ~~initial inspection~~

The primary purpose of the initial inspection of the UAV system ~~initial inspection~~ is to avoid ~~the~~ failure~~ of~~s in the ~~the~~ core components that cannot be restored quickly during the site investigation process~~. And~~. In addition, ~~the task is to detect~~this inspection establishes whether the main components, e.g., the flight control system, propellers, GNSS and compass, data and image transmission module, aerial gimbal system~~s~~ and camera, ground control station, terminal monitor, and remote control~~ler, etc.,~~ are working properly.

3.1.3 Preliminary route planning

In addition, if the location of a geo-hazard can be determined, it is ~~very~~ necessary to carry out ~~the indoor~~ preliminary route planning indoors based on ~~the~~ publicly available satellite maps, e.g., Google Earth, Bing Maps, AutoNavi Maps, etc., in the Mission Planner software package. Typically, the preliminary flight routes are simply designed as a regular grid pattern in plane view that ~~can~~ covers the whole ~~range of~~area affected by the geo-hazard (Fig. 4). In a word, preliminary route planning can help to save ~~the~~ time ~~of~~ spent on ~~on-site~~ detailed route planning on-site. Of course, if the location cannot be ~~known~~determined in advance, the indoor preliminary route planning ~~has to be ignored~~cannot be performed, but it does not affect the subsequent on-site investigation ~~by using~~using the UAV.

3.2 On-site investigation

Without a doubt, the on-site investigation is the most important step. We believe that there is an important principle to be followed;~~,~~ that is, the ultimate goal is fast and efficient collection of high quality ~~photos~~photographs of the geo-hazard for ~~the~~ subsequent ~~processing and applying~~processing and application, but ~~it must be the premise~~this collection must meet safety requirements. That is,~~ of security, i.e., ensuring~~ the safety of all on-site personnel, buildings and public facilities must be ensured ~~from the threat of using UAV~~, ~~as well as ensuring the own~~and the safety of the UAV system must be taken into consideration.

3.2.1 Environmental assessment

Before commencing a formal on-site investigation, ~~the~~ an environmental assessment is required to determine the UAV-based investigation scheme. Usually, an assessment of the ~~surrounding~~ environment surrounding the geo-hazard and its~~, the~~ characteristics, as well as ~~geo-hazard characteristics, and~~ the implementation conditions are needed. The former includes the local topography~~, local~~ and meteorological conditions, the distribution of aerial and ground facilities ~~distribution~~, visual range and intervisibility, flight range and other ~~judgments~~judgements. Assessment of the geo-hazard characteristics includes the topography of ~~disaster body~~the area affected by the hazard;~~,~~ its length, width, area, plane shape, and elevation change;~~,~~ and the risk it poses~~. And~~ . In addition, assessment of the implementation conditions includes the number of GNSS satellites ~~numbers~~, the ~~signal~~ strength and stability of the signal, the stability of the electronic compass ~~stability~~, the layout of ground control points (GCPs)~~,~~ and the location ~~of~~ used for takeoff~~-off~~ and landing~~, etc~~.

3.2.2 Two UAV-based investigation scheme

Based on a number of ~~practices~~previous investigations, two investigation schemes, including automatic and manual investigation, are ~~concluded~~ described as follows.

(1) Automatic scheme

~~Automatic scheme means that~~Using the automatic scheme, the UAV system is capable of autonomous flight in accordance with the routes established during detailed planning~~ routes~~, as well as automatic photo ~~shooting~~image collection, ~~by using~~using the UAV's own GNSS, compass and barometer~~ data~~. This scheme requires no manual intervention under normal ~~situation~~conditions~~, and is~~ and is therefore safer and more reliable than ~~the~~ manual ~~ways~~methods. At the same time, the acquisition of high quality ~~photos~~photographs ~~can be better guaranteed~~is more likely in this mode, ~~and~~ which can automatically meet some requirements of the ~~following~~ subsequent photogrammetric processing, e.g., the frontal and side overlap ratios between ~~photos~~photographs. In view of this, as long as there are more than five stable GNSS satellite signals in the geo-hazard area, the vast majority of emergency investigations should use the automatic investigation scheme~~.~~ ~~And~~. In addition, ~~it~~ this scheme is divided into six steps (Fig. 3), which are described below.

- **~~GCPs~~ L~~l~~ayout and measurement of GCPs**

To improve the accuracy of the photogrammetric processing results, the ~~setting~~ establishment and ~~measuring~~ measurement of GCPs in the field is essential (Niethammer et al., 2012; Lucieer et al., 2014; Niu et al., 2014). Usually, three to five GCPs should be ~~set~~ established in or around the geo-hazard (s~~S~~ee section 4.1 for details)~~,~~ ~~then t~~. R~~he r~~eal-time kinematic (RTK) differential Global Positioning System (DGPS) techniques~~ with~~, which have~~ the~~ advantage~~ of~~s including speed, ~~fast,~~ high efficiency and high precision, should be used to measure the 3D coordinates of all GCPs.

- **Assembly of the UAV system~~ assembly~~**

A m~~M~~odular design is used in our customized UAV system. The transport of d~~D~~isassembled components ~~can not only~~ saves ~~the~~ space~~ but also are~~, and the components are also protected from squeezing or cru~~a~~shing during the transport process. Therefore, after arriving at the disaster site, the modules need to be quickly assembled to form the complete UAV system~~ firstly~~.

- **Full inspection of the UAV system~~ full inspection~~**

After the system ~~is~~ has been assembled, all of the subsystems need to be fully checked ~~in the case of~~with the power turned on. The main purpose is to eliminate hidden dangers on the ground~~,~~ ~~then~~ and to ensure flight safety and normal photo ~~shooting~~image collection. This step is very important and cannot be ignored.

- **Detailed route planning**

Automatic investigations must rely on detailed route planning. If ~~the indoor~~ preliminary route planning has been carried out indoors (section 3.1.3), the detailed route planning should be based on this preliminary plan~~it~~.~~,~~ O~~o~~therwise, detailed route planning should be ~~done~~ carried out at the site. The core of this step is the determination of the route types according to the ~~geo-hazard~~ characteristics of the geo-hazard, as well as ~~the~~ accurate establishment~~setting~~ of the waypoint positions and ~~,~~the actions of the UAV, the aerial ~~gimbals~~gimbal system, and the camera~~s~~. See section 4.2 for details.

- **~~Parameters settin~~Setting of parameters~~g~~**

~~Parameter setting~~The setting of parameters is the last~~ and not negligible~~ step before flight, and it cannot be neglected~~. And ~~. Several~~some~~ important control parameters must be set according to the actual scene~~, t~~. Typically, the recommended flight rate is 5 to 20~~ meter~~ metres per second, and the camera ~~shooting~~image collection rate should not be less than 1 picture per second. It is important to remember to import all of the parameters into the flight control system onboard the UAV from the ground control station~~, and then t~~. These parameters can then take effect.

- **Autonomous flight and automatic photo ~~shooting~~image collection**

A relatively flat and open place should be selected as the takeoff~~ off~~ and landing site. After taking off, the UAV should follow the planned route for autonomous flight and automatic photo ~~shooting~~image collection under normal circumstances. During the flight, the status of the UAV and camera should be closely monitored (see section 4.3 for details). In the event of an abnormal state, the UAV should be switched to the manual mode ~~for emergency treatment~~to permit emergency response. After the flight is completed, the UAV system and the quality of the ~~photos~~photographs~~ quality~~ should be checked immediately.

(2) Manual scheme

~~Manual scheme means tha~~In the manual scheme,~~t~~ the entire UAV flight and the process of photo ~~shooting~~image collection~~ process have~~ has to be manually controlled ~~by using~~using the remote control~~ler~~. This scheme requires no route planning, which can save ~~the ~~time ~~of ~~in site investigation~~, but~~. However, it requires ~~a superb driving skill~~excellent piloting skills, and the flight safety and ~~photo ~~image quality are ~~susceptible~~frequently degraded;~~,~~ accordingly, the flight process should be monitored intensively. Therefore, ~~the ~~use of the manual scheme should ~~try to avoid~~be avoided~~, unless~~, although, in some places, such as mountainous areas or~~,~~ canyons~~, etc., with ~~, where the GNSS signals are unstable~~ even no GNSS signals~~ or even absent, or the scope of the geo-hazard is extremely limited, the manual scheme may be more suitable~~. And ~~. In addition, ~~it ~~this scheme is divided into 4 steps (Fig. 3), which are briefly described below.

- **Layout and measurement of GCPs ~~layout and measurement~~**

If there is no GNSS signal, the captured ~~photos~~photographs ~~do ~~will not ~~have ~~be associated with ~~GPS~~GNSS ~~data~~locations. In this case, the layout and measurement of GCPs ~~layout and measurement ~~is indispensable ~~to ~~in supporting the ~~following ~~subsequent photogrammetric processing. The setting of GCPs is the same as in the automatic scheme (s~~S~~ee section 4.1 for details). However, the use of a total station ~~measurement ~~is ~~the~~ ~~r~~recommended ~~technique to~~for measuringe the GCPs ~~under the situation of no~~where GNSS signals are absent.

- **Assembly of the UAV system~~UAV system assembly~~**

~~Same as in automatic scheme~~This step is the same as in the automatic scheme.

- **Full inspection of the UAV system~~UAV system full inspection~~**

This step is the same as in the automatic scheme.~~Same as in automatic scheme.~~

- **Manual flight and photo ~~shooting~~image collection**

Compared with the automatic scheme, the system status and the quality of the photographs should be ~~paid more attention to monitor~~monitored more carefully during the flight~~t process~~ (see section 4.3 for details)~~, as well as~~. ~~the quality of the photos shooting.~~ In addition, it is more important to check the system and the ~~photos~~photographs after the flight~~, especially for~~. In particular, ~~the photos,~~ the quality, scope and overlap rate of the photographs must~~are most need to~~ be evaluated.

3.3 On-site fast processing fast ~~and applying~~processing and application

After on-site UAV-based investigation is completed, the low-resolution ~~photos~~photographs ~~with low resolution~~ can be subjected to fast photogrammetric processing ~~by using~~using a portable computer ~~on the spot~~in the field. In general, in only ten to several tens of minutes, some rough results with ~~about~~approximately ~~meter~~ metre-level accuracy can be generated~~, e.g.,~~, including ~~the~~ digital surface models (DSMs), ~~the~~ digital orthophotos, and three-dimensional~~s~~ models. ~~this also means, f~~Fast processing focuses on the speed with which the results ~~generating speed~~are generated, not their precision. Although the accuracy is relatively poor, these emergency investigation results that can be obtained quickly in the field still ~~can well~~provide important support for the rapid on-site development of ~~the~~ preliminary ~~emergency treatment~~emergency response plans for ~~the~~ geo-hazards~~, and which~~. This high speed is the most prominent advantage of the UAV-based method for emergency investigation of single geo-hazards, compared ~~to~~ with~~the~~ traditional methods. ~~It~~This processing is divided into 4 steps (Fig. 3).

- **~~Photos pretreatment~~Preprocessing of photographs**

~~Photos pretreatment~~Preprocessing of photographs includes selecting photo~~albums~~s that cover~~s~~ the ~~appropriate range~~extent of the geo-hazard, removing poor-quality ~~photos~~photographs~~with bad quality,~~ (e.g., blurred images)~~, etc.~~, and checking the GNSS information ~~of~~ associated with the ~~photos~~photographs. In general, ~~the photos~~photographs ~~that~~ taken using the~~in~~ manual scheme require more time for pretreatment than those collected ~~by using~~using the automatic scheme.

- **Fast SfM processing and generation of coarse-precision results ~~generating~~**

Compared with traditional digital photogrammetry method, the SfM photogrammetric method is recommended ~~to be used for~~for use in the processing of UAV-based ~~photos~~photographs~~,~~ because it is simpler and more efficient (Snavely, 2008; Westoby et al., 2012; James et al., 2016)~~, e.g.,~~; for example, the camera position can~~could~~ be automatically calculated ~~only by using~~using only the GNSS data ~~o~~associated with~~f~~ each ~~photos~~photograph, ~~so~~ and information on the attitude of the~~the attitude data of~~ aircraft, such as its roll, pitch, and yaw, ~~etc.,~~obtained from the inertial measurement unit (IMU) ~~were~~ are no longer needed (Huang et al., 2017). The fast SfM photogrammetric processing consists of reducing the resolution of the original

~~photos~~photographs, ~~ resolution, making ~~performing ~~the ~~aerial triangulation and bundle adjustment, and generating ~~the ~~three-dimensional point clouds. ~~Then, b~~Using~~ased on~~ the dense point cloud, ~~the~~ coarse-precision results ~~of ~~for the geo-hazard, including ~~the ~~a DSM, ~~the ~~a digital orthophoto and ~~the ~~a three-dimensional model,~~, etc.~~ can be ~~further ~~generated. The Pix4Dmapper software package (Strecha et al., 2012; Mesas-Carrascosa et al., 2015) ~~was ~~is used to process the ~~photos~~photographs by SfM photogrammetric methods. ~~For ~~To enable fast processing, the lower image scale ~~were ~~is set ~~firstly, ~~first, ~~then ~~and only then is the GNSS ~~data of~~information associated with~~ every~~ each ~~photos~~photograph ~~was ~~used during the aerial triangulation and bundle adjustment~~, i.e.,~~. That is, the coordinates of the GCPs are~~were~~ not introduced during this stage to improve the absolute spatial position accuracy. Because the M8N GPS module with a nominal positioning accuracy of 2.5 m was used in our aircraft, the fast SfM processing results ~~were ~~generally displayed coarse ~~-~~precision ~~with~~and~~ a meter~~ metre-level error.

- **Coarse quantification and display of the geo-hazard**

Based on the coarse-precision results for the~~of~~ geo-hazard, ~~by using~~using geographic information system (GIS) or remote sensing (RS) software, the basic characteristics of the geo-hazard can be quantified~~, e.g.~~. These characteristics include~~,~~ length, width, area, and elevation change~~, etc~~. In addition, the three-dimensional scene of the geo-hazard and its surroundings can be vividly displayed.

- **Supporting the development of the preliminary ~~emergency treatment~~emergency response plan**

The quantitative characteristics and the intuitive three-dimensional scene of the geo-hazard provide the basis and macro-level information for the rapid on-site development of ~~the ~~a preliminary ~~emergency treatment~~emergency response plan. ~~As to the results with~~The~~ meter~~ metre-level error of the results~~,~~ ~~basically~~ essentially does not affect the ~~feasibility ~~appropriateness of such ~~the ~~qualitative~~-based~~ plans.

3.4 Indoor comprehensive ~~processing and applying~~processing and application

The d~~D~~esign of ~~the ~~detailed ~~emergency treatment~~emergency response plans is an important ~~basis for~~step in the implementation of disaster prevention and mitigation efforts, so the basic data such as terrain representations and~~,~~ orthophotos that are used in the design must be accurate and clear. The purpose of comprehensive processing is to obtain such high quality results~~ data~~. ~~So, the~~Therefore, the original ~~photos~~photographs ~~would be~~are reprocessed ~~by using~~using high-performance desktop computers or graphic workstations indoors. The comprehensive processing generally takes one to several hours, but all of the results have~~ centimeter~~ centimetre-level accuracy ~~by introducing~~because the GCPs are introduced. ~~This also means,~~ C~~c~~omprehensive processing focus on the~~ results precision~~ precision of the results, ~~not the speed~~rather than the speed with which they are generated. It is divided into 3 steps (Fig. 3).

- **Comprehensive SfM processing and generation of high-precision results~~ generating~~**

The comprehensive SfM processing workflow is the same as that used in the fast processing~~, t~~. The differences ~~include~~ are that the original ~~photos~~photographs with high resolution are used, and the GCPs are introduced before ~~generating~~ the point clouds are generated. Accordingly, the products~~results~~ of the comprehensive SfM processing are the same as those of the fast processing~~, i.e.~~. That is,~~,~~ ~~the~~ DSMs,~~ the~~ digital orthophotos and ~~the~~ three-dimensional model~~, etc.,~~s are produced, but ~~they~~ these products are high-precision and high-definition. Likewise, Pix4Dmapper software ~~was~~ is used for the comprehensive SfM processing. ~~Firstly,~~ First, the full-~~-~~scale ~~photos~~photographs with GNSS ~~data were~~information are used~~, and then~~. Subsequently, during the process of aerial triangulation and bundle adjustment~~ process~~, the GCPs ~~were~~ are introduced to improve the absolute spatial position accuracy. Because the 3D coordinates of the GCPs ~~were~~ are measured ~~by~~ using the RTK-DGPS technique~~ with~~ and have a nominal positioning accuracy of 2 cm, the comprehensive SfM processing results were generally high-precision with ~~a centimeter~~centimetre-level error.

- **Accurate quantification and display of geo-hazards**

Using the high-precision and high-definition results for the~~of~~ geo-hazard, the basic characteristics of the geo-hazard can be accurately quantified. Accordingly, the three-dimensional scene of the geo-hazard and its surroundings can be more accurately and vividly displayed.

- **Supporting the design of ~~the~~ detailed ~~emergency treatment~~emergency response plans**

Based on the accurate quantitative characteristics, ~~with the high-precision and high-definition DSM, orthophoto, and three-dimensional scene of geo-hazard,~~ a large-~~-~~scale topographic map and plan can be produced, and accurate design data can be obtained~~, –~~ from the high-precision and high-definition DSM, orthophoto, and three-dimensional scene of the geo-hazard. This information provides important~~which can well~~ support for the design of ~~the~~ detailed ~~emergency treatment~~emergency response plans.

4 Key techniques and methods

4.1 ~~GCPs layout and measurement~~Layout and measurement of GCPs

Due to the limited precision of the GNSS units carried by UAVs (~~,~~ e.g., the M8N GPS module~~ which was~~ onboard~~ used in~~ our aircraft has~~d~~ a nominal positioning accuracy of 2.5 m), it is necessary to set and measure GCPs in the field ~~at the same time with~~before the UAV flight and ~~photo shooting~~image collection, to improve the accuracy of the photogrammetric processing results. In addition, the ~~GCPs~~ layout and measurement of the GCPs should be implemented quickly and efficiently, but the results should be high-precision.

~~Firstly,~~ First, within the ~~flight range~~area covered by the flight, some obvious ground feature points, e.g., house corners, road intersections, exposed bedrock, etc., can be ~~directly~~ used directly as GCPs, as long as they can be clearly identified both on the ground and on ~~photos~~photographs. Otherwise, several GCP markers that can also be identified i~~o~~n ~~photos~~photographs need to be placed on the ground. Usually, for ~~the~~ single geo-hazards, only three to five GCPs need to be ~~se~~established~~t~~ in or around the geo-hazard, and the distribution should be as uniform as possible, e.g., networks made up of ~~constituting the~~ equilateral triangles or quadrilateral~~ networks~~s are~~is~~ appropriate. It is worth noting that~~,~~ the layout of the GCPs ~~layout~~ should be completed before the UAV flight and ~~photo shooting~~image collection, to ensure that the ~~photos~~photographs contain all of the GCPs.

~~As for the GCPs measurement~~Regarding the measurement of the GCPs, the RTK-DGPS technique,~~s with the~~ which has advantages in that it is~~ advantage of~~ fast~~, –~~ and has high efficiency and high precision, should be used preferentially as long as there are stable GNSS signals, regardless of whether ~~in~~ the automatic or manual scheme is used, to measure the 3D coordinates of all of the GCPs. On the other hand,~~While~~ in mountainous areas, canyons, etc., with unstable or even no GNSS signals, the total station measurement techniques would be a good choice, and sometimes even ~~sometimes~~ the non-prism total station measurement techniques may be the only option (Huang et al., 2017)~~. And~~. Moreover,~~then,~~ the measurement can be carried out at any time during the on-site investigation process, but if it is performed at the same time as the collection of ~~photo shooting~~ images by the UAV, the GCP~~s~~ markers should not be covered.

4.2 Route planning

According to the characteristics of ~~the single~~individual geo-hazards, proper route type selection and accurate motion design are key ~~to~~ in ensuring~~e~~ the safety and efficiency of UAV-~~–~~based emergency investigation. Based on a number of ~~practice~~examples~~s~~, three typical route types are summarized as follows (~~Fig.5~~Fig. 5).

(1) Planar grid pattern for slightly inclined slopes (Fig. 5a). This pattern is suitable for geo-hazards that cover~~ the~~ large ~~-~~areas (typically~~y, e.g.,~~ several million square~~ meter~~ metres~~ area~~) ~~geo-hazard~~ on the gentle slopes (~~the slope is~~ typically less than 40 °), such as gently~~e~~ ~~-~~inclined landslide bodies. The primary purpose of the emergency investigation for this kind of disaster is to obtain a digital terrain model and an orthophoto. Therefore, the ~~planning route~~planned route consists of a regular planar grid ~~which can cover~~that covers the whole planar area of the geo-hazard~~. And~~. In addition, the camera lens always points vertically down to the ground (i.e., the lens orientation ~~keeps~~ is held at 0 °). It is~~'s~~ worth noting that the flying height of the route should be dynamically adjusted to meet the elevation changes of the disaster and slope~~, i~~. In principle, it is advisable to ~~keep the flying height of the UAV~~maintain the UAV's flying height at a constant distance (i.e., the *h* in Fig. 5a) from the ground, and practice shows that *h* in 50 m ~ 100 m is proper. ~~Because l~~Lower flights require~~s~~ ~~more routes~~longer routes and ~~longer~~ increased flight time, and~~ the~~ flight safety ~~will decrease~~decreases;~~,~~ conversely, higher flights ~~will r~~educe the resolution of ~~photos~~photographs and the processing results.

~~–~~(2) Vertical grid pattern for steep slopes (Fig. 5b): This pattern is suitable for ~~the~~ geo-hazard~~ which~~s that are developed on~~ the~~ steep slopes (~~the slope is ~~typically ~~more ~~greater than 60 °), such as dangerous rock masses on~~ the~~ cliffs. ~~The e~~Emergency investigation~~ for~~s of this kind of disaster should aim at obtaining ~~the facade ~~orthophotos of the facade and 3D models, rather than digital terrain and vertically downwards~~s~~ orthophotos. In this case, the ~~planning route~~planned route consists of a regular vertical grid which ~~can cover~~that covers the whole facade area of the geo-hazard~~. And ~~. In addition, the camera lens always points horizontally to the disaster body (i.e., lens orientation ~~keeps ~~is held at 90 °). The plane positions of all of the horizontal routes can overlap, but they are at different altitudes. In addition, it is advisable to keep the UAV flying at a constant distance (i.e., the *d* in Fig. 5a) from the ~~disaster body~~area affected by the disaster (practice shows that~~, ~~ a *d* of~~in~~ 40 m ~ 80 m is proper).

(3) Combined grid pattern for transitional terrain (Fig. 5c): This pattern is suitable for~~ the~~ geo-hazard ~~which~~s that are ~~developed ~~located on ~~the ~~transitional terrain~~, i.e., including~~ and include both gentle and steep slopes, such as ~~the combination of~~a dangerous rock mass on ~~the ~~a cliff and the corresponding collapse accumulation mass on the gentle slope below. The main purposes of emergency investigation for~~of~~ this kind of disaster~~, is not only~~ are to obtain~~get~~ ~~the ~~a digital terrain model and an orthophoto~~, but also~~, as well as~~ to get the~~ a facade orthophoto and a 3D model. Therefore, the combined grid pattern ~~of planning route ~~should be adopted for the planned route. That is,~~, i.e., using~~ a regular planar grid is used to cover ~~the ~~areas with gentle slopes, and a vertical grid is used to cover ~~the ~~areas with steep slopes. Accordingly, the camera lens points vertically down to the ground~~ at the ~~ within the part with the~~of~~ planar grid (i.e., the lens orientation ~~keeps~~ remains at 0 °), and gradually ~~lifts ~~rises from the low ~~route ~~position to the high ~~route ~~position in~~at~~ the part with the~~of~~ vertical grid (i.e., the lens orientation changes from 0 ° to 90 °). The flying height *h* and flying distance *d* in ~~Fig.5~~Fig. 5c can be set as in the planar and vertical grid patterns, respectively.

In particular applications, the ~~planning route~~planned route should be selected~~, combined or flexible changed~~ from the~~ above~~ three typical route types listed above; alternatively, these routes can be changed flexibly or combined,~~,~~ based on the spatial distribution characteristics of the specific geo-hazard being investigated. ~~But ~~However, in any case, the ~~planning route~~planned route must meet the requirements that the obtained pictures’ frontal overlap ratios must be~~are~~ at least 75%, and the side overlap ratios must be~~are~~ at least 60%. ~~Otherwise ~~Otherwise, ~~it will seriously affect ~~the scope and accuracy of the post-processing results will be seriously affected.

In addition, the detailed route planning in the field should also account for the following points.~~note:~~

①Whether a preliminary route planning has been carried out or not, it is necessary to accurately calibrate the flight route and range based on the actual location~~ of~~s from the UAV's own GNSS data.

②The route coverage should be larger than the actual area affected by~~distribution scope of~~ the geo-hazard~~,~~ to ensure that the ~~photos~~photographs of the disaster ~~have enough overlap rates~~overlap sufficiently.

③The starting point and route should be ~~set~~ established near the foot of the disaster body, and the ~~ending~~ end of the route and the ending point should be set near the top~~, so as to keep the flying of~~. Thus, the altitude of the UAV will progress~~which is~~ from low to high altitude during the emergency investigation (Fig. 5)~~,~~ ~~because t~~. The UAV~~ will~~ is ~~be~~ more stable during ~~the~~ upward flight, which is more conducive to taking~~e~~ clear ~~photos~~photographs.

④After careful~~ly~~ checking~~ed~~, the ~~planning route~~planned route must be imported into the flight control system of the UAV to take effect.

4.3 Flight and ~~shooting~~image collection process control

It is essential to carry out the pre-flight inspection after importing the accurate ~~planning route~~planned route data and setting the flight parameters~~. And~~ . This inspection~~it~~ mainly includes assessments of the battery capacity, GNSS signal, propeller, aerial ~~gimbals~~gimbal system, camera, data and image transmission modules, ~~remote controller~~remote control and the ground control station~~, etc~~. The~~Then, using~~ UAV can then be used to take ~~photos~~photographs for the emergency investigation of single geo-hazard~~s can be put into effect,~~ . D~~d~~uring~~ the~~ flights, it is best to have three technical staff involved in the implementation to ensure the flight safety and photo quality. The~~A~~ primary operator, in the automatic scheme, is responsible for monitoring the flight and ~~shooting~~image collection state through the ground control station during the normal autonomous process~~,~~ or switching to ~~manually operated~~manual operation of the flight and photo ~~shooting~~image collection in the event of an abnormal state~~.; in~~ . When the manual scheme is in use, the primary operator is always responsible for manually ~~operating~~ performing the taking off, flight and landing of the UAV using the~~by~~ ~~remote controller~~remote control. The~~A~~ primary supervisor~~,~~ is always responsible for monitoring the real-time flight images and changes to the important parameters (~~e.g.~~ e.g., the height, the speed, the battery capacity, and the GNSS signal)~~, etc.) changes~~ through the ground terminal monitor~~, and~~ . The primary supervisor immediately notifies the ~~flying states to the~~ primary operator of changes in the UAV’s flying state, regardless of whether ~~in~~ the automatic or manual scheme is in use. ~~Another~~ Meanwhile, the deputy operator~~ion~~ and monitoring personnel, in the two schemes, is responsible for real-time tracking of the posture changes of the UAV and observing the surroundings ~~on the forward route~~ahead of the UAV through ~~the~~ a ~~telescope~~spotting scope, ~~so as to~~to detect the aircraft anomalies or flight obstacles as early as possible, and promptly notifies the primary operator for ~~emergency treatment~~emergency response; in the manual scheme, this staff member is also responsible for manipulating the camera lens and ~~shooting~~image collection ~~photos~~using ~~by~~ another ~~remote controller~~remote control.

4.4 SfM photogrammetric processing

At present, ~~the~~ traditional digital photogrammetry and the newly developed SfM photogrammetric method, which is based on computer vision algorithms, can both be used for the processing of UAV images, but the latter is ~~more simple~~simpler and more efficient. ~~Because the~~ In contrast to traditional ~~photogrammetry methods~~photogrammetric methods, which require ~~not only~~a single stereo pair~~, but also~~ of images in addition to ~~–~~the 3D locations and ~~pose~~ orientations of the cameras~~s,~~ or the 3D locations of a series of GCPs, ~~to be known, in contrast,~~ the SfM technique ~~only~~ requires only multiple~~,~~ overlapping ~~photos~~photographs as input (Westoby et al., 2012). The principles and workflow of SfM ~~can be understood from~~have been described by Snavely (2008), Snavely et al. (2008), and Westoby et al. (2012). The Pix4Dmapper software package ~~was~~ is used for the SfM photogrammetric processing, which can convert a large number of images into georeferenced 2D DSMs, digital orthophotos and 3D models (Huang et al., 2017).

When the SfM photogrammetric processing method is used to process the ~~photos~~photographs that are captured by ~~the~~ UAVs during the emergency investigation of ~~the~~ single geo-hazards, it is divided into ~~on-site fast processing~~on-site fast processing and indoor comprehensive processing (~~Fig.3~~Fig. 3). In addition, the results of the SfM photogrammetric processing should also be targeted~~ for~~ to the different types or characteristics of the geo-hazard~~,~~; ~~the results of SfM photogrammetric processing should also be targeted,~~ e.g., for the type of ~~disaster~~event shown in Fig.~~ure~~ 5a, the main results should be ~~the~~ a digital terrain model and an orthophoto; for the type of event shown in Fig.~~ure~~ 5b, the core results ~~can be~~will likely be a~~ the~~ facade orthophoto and a 3D model; for the type of event shown in ~~Figure~~ Fig. 3c, the results should include ~~not only the~~a digital terrain and orthophoto~~, but also~~, as well as ~~–the~~ a facade orthophoto and a 3D model.

5 Application examples

5.1 Emergency investigation of a slightly inclined landslide

~~At the beginning of~~In early September 2014, ~~under the influence of continuous heavy rainfall,~~ a ~~whole~~ mass movement ~~happened~~occurred~~ to~~ under the influence of continuous heavy rainfall and resulted in a landslide in the Three Gorges ~~Reservoir Area~~Reservoir area~~, which~~. This landslide represented a serious~~ly threatened~~ threat to the ~~safety of~~ surrounding houses, ~~the~~ highway traffic and the ~~villagers'~~ life and property of the local residents (~~Fig.6~~Fig. 6a). ~~By e~~Environmental assessment showed that~~,~~ the landslide had a gentle slope and small size, but ~~with a large potential threats range~~it threatened a large area. In addition, the environment was rather open and the GNSS signal was stable. Therefore, the automatic investigation scheme was adopted.

~~Firstly,~~ First, ~~the route planning was performed~~a route was planned according to the pattern of Fig. 5a based on the position of the ~~disaster~~ mass movement and its ~~influence area~~extent. At the same time, 4 GCPs were selected around the landslide (Fig. 6a)~~, the~~, and RTK-DGPS was used ~~for the measurement o~~to measure~~f~~ the 3D coordinates of these GCPs~~, the~~. The establishment and measurement of the GCPs ~~layout and measurement~~ took ~~about 5~~approximately 50 minutes. Then, by autonomous flight and automatic photo ~~shooting~~image collection, 66 ~~photos~~photographs were~~as~~ captured~~, togethe~~. Including~~r with~~ route planning and UAV preparation, the entire working time ~~by using~~using the UAV ~~only took~~required only ~~about 3~~approximately 30 minutes. Finally, ~~by~~ using SfM photogrammetric processing, an orthophoto with ~~the~~ a ground sampling distance (GSD) of 4.25 cm (Fig. 6a)~~,~~ and a 3D texture model (Fig. 6b) were generated. For simplicity, the 4 GCPs were used as checkpoints for accuracy assessment, and the root-mean square error (*RMSE*) values were calculate~~d. Results~~d. The results showed that~~,~~ the fast SfM processing required only~~only took~~ 28 minutes, but the spatial errors were 3.118 m (X_{error} = 2.327 m, Y_{error} = 2.862 m, Z_{error} = 4.165 m). ~~On the contrary,~~ In contrast, the comprehensive processing took 65 minutes, ~~while~~ and the spatial errors were reduced to 0.038 m (X_{error} = 0.031 m, Y_{error} =0.038 m, Z_{error} = 0.045 m)~~,~~ because the GCPs were introduced during the SfM photogrammetric processing. In short, all of the on-site work, including the UAV-based investigation, the ~~GCPs~~ layout and measurement of the GCPs, and the fast photogrammetric processing, ~~spent~~ required a total of 78 minutes~~. And~~ . In addition, then, an orthophoto and a 3D texture model with an error of ~~about 3~~approximately 3 m ~~could be~~ ~~was~~were generated on-site~~, which~~. These products ~~could give the~~provided ~~basis and~~ macro-level information about the landslide and its surroundings.

Based on the results of the above emergency investigation, combined with ground investigations, the characteristics and effects of the landslide were quickly interpreted (Fig. 6c) and evaluated~~, t~~. These products revealed the formation of~~he conclusions included:~~ obvious head~~-~~ and ~~two~~ side~~-~~ scarps ~~formed,~~ . Moreover, the drainage ditch ~~which~~that was located within the landslide was completely destroyed, and~~,~~ ~~the collapse of the~~ the front loose soil mass collapsed and blocked the gully, forming~~ed~~ a free face~~, and led~~ and leading to the emergence of a large number of tension cracks~~, all indications~~ . All of these indications suggested ~~were~~ that the landslide ~~had an obvious and whole sliding~~represented an obvious mass movement, and ~~the~~that~~n~~ the landslide ~~had been~~was in an unstable state. In addition, the landslide ~~had been~~ was a direct threat to the houses which were located ~~outside~~ adjacent to the right boundary of the landslide. Moreover, as the loose soil mass ~~in~~ at the front of the landslide continuously accumulated in the gully, ~~the~~ a debris flow ~~disaster~~ would be easily triggered by heavy rainfall, then seriously threatened the house and highway. Based on the ~~above~~ conclusions above, ~~the following emergency treatment~~emergency response measures were put forward~~:~~ , including using professional monitoring techniques ~~including~~ such as GNSS, extensometers, rain gauges, and ground-based inspection to continuously track the process of deformation and induction~~er~~ of the landslide; ~~building~~ establishing ~~the~~ a citizen science-based monitoring and prevention system ~~operated by mass people~~, which means to ~~arrange~~ encourage the surrounding ~~masses~~ population to ~~observe the deformation signs of~~watch for signs of deformation within the landslide body, e.g., ~~the~~ cracks, ~~soil~~ collapses, and ~~houses~~ cracks in houses~~, etc.~~, especially ~~in the event of~~in association with heavy or continuous rainfall; and developing ~~the~~ an emergency evacuation ~~program~~ programme to ensure the orderly avoidance and reduction of losses before ~~the~~

additional movement~~landslide~~ occurs.

This application shows that the results of UAV-based emergency investigation can provide a ~~more macro~~large-scale perspective for use in the comprehensive evaluation of the characteristics of single geo-hazard~~ characteristics~~s and their potential impacts, which can make up for the defect ~~that ~~of ~~the~~ ground-based investigations, which focus ~~more ~~on~~ partial~~ parts of geo-hazards but ignore~~s~~ the whole.

5.2 Emergency investigation of a dangerous rock mass on a steep cliff

In September 2015, a dangerous rock mass was~~ found~~ noted above a provincial highway on the left bank of the Yangtze River in the Three Gorges area~~, which~~. This rock mass presented~~ was~~ a serious threat to the safety of the highway traffic and ~~the ~~shipping along the Yangtze River~~ shipping~~ (Fig. 7a). Only one side of the dangerous rock mass was attached to a~~ vertical~~ steep cliff (Fig. 7b), and it was located at least 100 m away from the lower highway, which ~~led ~~caused the site to ~~the ~~be inaccessible ~~of ~~to human beings. Therefore, the use of UAVs for emergency investigation ~~would be the priority~~was prioritized. ~~Thanks to the~~Because a stable GNSS signal existed at the study site, the automatic investigation scheme was adopted.

~~Fig.7~~Fig. 7. The results of a UAV-based emergency investigation for a dangerous rock mass on steep cliff. (a) Overview photo; (b) right side photo of the dangerous rock mass; (c) 3D texture model of the whole scene; (d) 3D texture model of the dangerous rock mass.

~~Firstly, ~~First, ~~the ~~route planning was performed according to the pattern ~~of ~~shown in Fig. 5b. At the same time, 3 GCPs were ~~arranged ~~established along the highway and measured with the RTK-DGPS technique (Fig. 7c)~~. And ~~. In addition, it should be noted that, because the three GCPs were ~~nearly ~~located in nearly a straight line, ~~for ~~given the limited environment, which c~~ouldn’t~~ould not meet the processing requirements, another GCP was established~~ which located~~ on ~~the ~~top of a hill behind the cliff~~ was introduced~~ (Fig. 7c), and its coordinates were measured according to the pre-existing topographic map. The layout and measurement of the ~~Three ~~3 GCPs~~ layout and measurement just~~ took only ~~about 2~~approximately 25 minutes.~~ Then, t~~ The camera lens direction was then set at ~~about 4~~approximately 45 ° to the steep cliff~~,~~. Through~~by~~ autonomous flight and automatic photo ~~shooting~~image collection, 104 ~~photos~~photographs were captured~~, t~~. Together with route planning and UAV preparation, the entire working time ~~by using~~using the UAV took 35 minutes. Finally, in order to obtain high-precision results for the design of the detailed ~~emergency treatment~~emergency response plan, the comprehensive SfM processing was ~~directly ~~used directly, which took ~~about 1~~approximately 100 minutes, and ~~the ~~a DSM and a 3D texture model (~~Fig.7~~Fig. 7c, d) with ~~the ~~a GSD of 5.47 cm were generated. Similarly, the 4 GCPs were used as checkpoints for accuracy assessmen~~t. Results~~t. The results showed that~~,~~ the spatial errors were 0.237 m (X_{error} = 0.218 m, Y_{error} = 0.183 m, and Z_{error} = 0.310 m);~~,~~ i.e., the accuracy was~~a~~ sub-meter-level~~ accuracy~~, ~~the main reason was that~~primarily because the GCP on the hilltop ~~of a hill~~ could not be accurately measured. Even so, the sub-meter level accuracy ~~had been~~was able to meet the requirements of quantifying the size and generating large-scale topographic maps of the dangerous rock mass for use in ~~its~~ the design of emergency control ~~design~~measures~~,~~ and would not have a substantial impact on the conclusions. Moreover, all of the ~~investigation~~ investigative work, ~~including~~ extending from the on-site UAV-based investigation to the generation of high-precision results~~, generation, just~~ ~~took~~required only ~~about 2~~approximately 2 hours and 15 minutes~~, which was impossible for~~. Such a short time period could not be achieved through ~~manual~~ ground-based investigation, especially for an isolated dangerous rock mass on a cliff.

In view of the DSM and the 3D mode~~l, results~~l, the results showed~~:~~ that the dangerous rock mass was~~is~~ 24 m high, 12 m wide, and 12 m thick and had a volume of 3456 m^3 ~~in volume~~, and ~~the~~ its exact distance ~~of which~~ from the highway ~~is~~ was 110 m~~; t~~. The lower and upper part of the rock mass had fallen, so it ~~had lost the support completely~~ was completely unsupported. The left and right boundary cracks ~~had been~~were ~~completely~~ fully connected. All of these signs indicated that the dangerous rock mass was in an unstable state~~. And~~ . Therefore~~then~~, ~~above~~ the relevant emergency investigation results described above ~~had been~~ were submitted to the technical department ~~for~~ to support the design of a detailed ~~emergency treatment~~emergency response plan ~~design~~.

In this case, the UAV ~~worked as~~provided the only ~~alternative~~ reasonable means of performing an emergency investigation ~~for~~ of this dangerous rock mass on a steep cliff, and the DSM and the 3D texture model provided both ~~the whole~~full and partial~~the part~~ information ~~which~~ that ~~could well~~ supported the design of the ~~emergency treatment~~emergency response ~~design~~.

5.3 Emergency investigation of a combined slope ~~with~~ on transitional terrain

In January 2016, some rock~~-~~falls occurred on a~~n~~ ~~artificial~~ high and steep artificial slope that had been controlled in the Three Gorges ~~Reservoir Area~~Reservoir area, which ~~was~~ presented a serious threat to the safety of the traffic on a ~~lower~~ provincial highway ~~traffic~~ and the shipping on the Yangtze River ~~shipping~~ below (Fig. 8a). The slope ~~is~~ was located on the left bank of a tributary estuary of the Yangtze River, ~~and three sides of it are~~and it was surrounded by the rivers on three sides. Geomorphologically, the slope above the highway ~~is made up~~ consisted of five steep cliffs (Fig. 8b), ~~and the~~whereas the ~~part~~ portion of the slope below the highway has a gentle slope but is surrounded by the rivers. It could be~~en~~ seen that it was almost impossible to implement ~~the~~ a ground-based investigation to ~~find~~ identify all of the potential geo-hazards, so the UAV was used and the automatic investigation scheme was adopted.

~~Firstly,~~ First, ~~the~~ route planning was performed ~~according to~~based on the pattern ~~of~~ shown in Fig. 5c. At the same time, four GCPs were arranged along the winding highway and measured with the RTK-DGPS technique (Fig. 8a)~~, the~~. The ~~GCPs~~ layout and measurement of the GCPs ~~took~~ required ~~about 4~~approximately

40 minutes. ~~Then, by ~~Using autonomous flight and automatic photo ~~shooting~~image collection, 75 ~~photos~~photographs ~~was ~~were then captured~~, t~~. Together with route planning and UAV preparation, the entire working time ~~by using~~using the UAV ~~only ~~took only ~~about 5~~approximately 50 minute~~s.. ~~s. Finally, ~~by ~~using SfM photogrammetric processing, ~~the ~~an orthophoto, a DSM and a 3D texture model with a~~the~~ GSD of 5.02 cm were generated. The 4 GCPs were used as checkpoints for accuracy assessmen~~t. Results~~t. The results showed that~~,~~ the fast SfM processing took 40 minutes and~~,~~ the spatial errors were 3.686 m (X_{error} = 3.173 m, Y_{error} = 3.401 m, Z_{error} = 4.485 m). ~~On the contrary, ~~In contrast, the comprehensive processing took 95 minutes, ~~while ~~and the spatial errors were reduced to 0.061 m (X_{error} = 0.053 m, Y_{error} = 0.060 m, Z_{error} = 0.069 m) by introducing the GCPs. In short, all of the on-site work ~~spent ~~required a total of 90 minutes.

~~-~~Based on all of the results, mainly the high-resolution 3D texture model~~, ~~, three potential geo-hazards were identified on this~~e~~ ~~whole ~~slope (Fig. 8)~~: a~~. Above the highway, within the 4th section of the cliff and the left part of the 5th section of the cliff~~s~~, several ~~isolated dangerous~~dangerous isolated rock masses had formed because of the continuous development of ~~the ~~tension cracks~~; i~~. In the upper part of the 2nd section of the cliff and the left part of the 3rd section of the cliff~~s~~, a large number of broken rock masses that ~~were easily dropped~~could fall easily ~~for the~~had developed due to the continuous development of two sets of tension cracks.~~;~~ B~~b~~elow the highway, ~~there was ~~a tension crack existed on the right side of the slope. In addition, the detailed characteristics of ~~every ~~each section of the cliff~~s~~ could be accurately measured (Fig. 8b). The relevant results from the emergency investigation ~~results had been~~were submitted to the relevant departments for risk assessment and the design of control measures~~ment~~.

In this case, the flexibility and wide applicability of the UAV ~~had been~~were fully prove~~nd, which~~. UAV-based methods can~~ could~~ provide ~~not only the ~~high-definition visual 3D scenes and models~~, but also~~, as well as~~ the~~ accurate quantitative basic terrain data, ~~to well supporting~~thus providing strong support in the evaluation~~ or the design~~ of single geo-hazards or the design of relevant control measures.

According to ~~above ~~the application examples described above, it ~~could ~~can be seen that~~, the on-site~~ UAV-based investigations ~~could ~~can be completed on-site within 1 hour~~, and i~~. If needed, coarse-precision results with~~ meter~~ metre-level error ~~could ~~can also be generated on-site ~~by ~~using fast SfM processing, usually within 1 hour. ~~That is to say,~~That is, ~~by using~~using UAV~~-~~-based emergency investigation methods and SfM photogrammetric processing technology, ~~the ~~macro-scale and three-dimensional information ~~of ~~on a single geo-hazard~~ could~~ can be obtained within 2 hours, which ~~could ~~can support the rapid on-site development of ~~the ~~preliminary ~~emergency treatment~~emergency response plan~~s, and it was~~. This rapidity is the most prominent advantage of this UAV~~-~~-based method in comparison with~~, compared to~~ the traditional methods. Moreover, by introducing the GCPs into the comprehensive SfM processing, ~~the ~~high-precision results with ~~centimeter~~ centimetre-level error ~~could ~~can also be obtained~~, which~~. These high-precision results ~~could ~~can support the design of ~~the~~ detailed ~~emergency treatment~~emergency response plans, and the processing time required was ~~generally took~~typically several hours.

6 Conclusions

This paper comprehensively ~~expounds~~ describes the method of using UAVs for emergency investigation of single geo-hazards.~~,~~ T~~t~~he main conclusions are summarized ~~as follows~~below.~~:~~

(1) According to the requirements of emergency investigation, combined with ~~the~~ comprehensive consideration of applicability, security, stability and economy, the UAV system ~~is~~ used is custom-built~~customized, and i~~. Its core functions and modules include~~:~~ a four-axis and eight-rotor carbon ~~fiber~~ fibre airframe; a ~~set of~~ stable ~~and~~, reliable, and open source ~~and matched~~ flight control hardware system that is compatible ~~and~~ with the ground control station software, which ~~can well~~ provides comprehensive support for route planning, autonomous flight and automatic photo ~~shooting~~image collection; an ordinary digital camera with a relatively high number of~~er~~ pixels or a single-lens reflex (SLR) camera, which is ~~is~~ ~~satisfied~~ satisfactory for ~~the shooting~~image collection (~~, and~~ a three-axis brushless aerial gimbal system is used to ensure the ~~clear shooting~~collection of clear images and the flexible adjustment of the camera lens direction); and a ground surveillance subsystem, which is used to monitor the flight of the UAV system and the collection of images ~~shooting~~by this system ~~process of UAV system~~.

(2) The ~~implementation~~ process of using the UAV to perform emergency investigations of~~e the~~ single geo-hazards can be divided into four steps, i.e., indoor preparation, site investigation, ~~site fast processing~~on-site fast ~~and applying~~processing and application, and indoor comprehensive ~~processing and applying~~processing and application. It ~~must~~ should be noted that~~,~~ the automatic or manual scheme should be ~~determined~~ selected ~~firstly~~ first during the on-site investigation, according to the environmental assessment~~.~~ ~~And~~. In addition, as long as there are more than five stable GNSS satellite signals in the geo-hazard area, the vast majority of emergency investigations should use the automatic scheme. The ~~GCPs~~ layout and measurement of GCPs is also ~~a~~ vital ~~work for the purpose of~~in improving the accuracy of the photogrammetric processing results. The aim of fast processing is to support the rapid on-site development of ~~the~~ preliminary ~~emergency treatment~~emergency response plans for ~~the~~ geo-hazards, ~~and~~ whereas the ~~indoor~~ comprehensive processing, which is performed indoors, is intended to support the design of ~~the~~ detailed ~~emergency treatment~~emergency response plans. The SfM photogrammetric method is recommended ~~to~~ for use ~~for~~ regardless of whether the fast processing or the comprehensive processing is employed.

(3) Mastering the key techniques and methods contribute to ~~a~~ better use of UAVs for emergency investigation of single geo-hazards. The following points are worth noting.~~:~~ Before the on-site flight and ~~shooting~~image collection, three to five GCPs should be ~~set~~ established in or around the geo-hazard, and their

distribution should be as uniform as possible, ~~e.g.,~~i.e., ~~constituting the~~they should constitute equilateral triangles or a quadrilateral network. The RTK-DGPS technique~~s~~ should be used preferentially as long as there are stable GNSS signals~~, and the t~~, whereas total station measurement techniques would be a good choice in ~~the~~ areas with unstable or even no GNSS signals~~;~~. Proper route planning is key to ensure the safety and efficiency of ~~UAV based~~UAV-based emergency investigations. Three typical route types are recommended~~,~~. The planar grid pattern is suitable for ~~the large area~~ geo-hazards that cover large areas on ~~the~~ gentle slopes, the vertical grid pattern is suitable for ~~the~~ geo-hazards that are~~which~~ developed on ~~the~~ steep slopes, and the combined grid pattern is suitable for ~~the~~ geo-hazard~~ which~~s that occur~~ developed~~ on ~~the~~ transitional terrain~~,~~ ~~i.e.~~, which~~,~~ ~~including~~ includes both gentle and steep slopes. In particular applications, the ~~planning~~ planned route should be selected, combined or flexibly~~e~~ changed from the ~~above~~ three typical route types mentioned above, based on the spatial ~~distribution~~ characteristics of ~~specific~~ individual geo-hazards. ~~But~~ However, in any case, the ~~planning route~~planned route must ~~meet the requirements~~ ensure that the ~~obtained pictures'~~ frontal overlap ratios of the obtained pictures are at least 75%, and the side overlap ratios ~~are~~ should be at least 60%.~~;~~ It is essential to carry out a pre-flight inspection after importing the accurate ~~planning route~~planned route data and setting the flight parameter~~s, and~~ s. Moreover, during ~~the~~ flights, it is best to have three technical staff members ~~involved in the implementation~~on hand to ensure ~~the~~ flight safety and ~~photo~~ image quality. When the SfM photogrammetric processing method is used, the results should also be targeted according to the ~~different~~ types or characteristics of ~~the~~ different geo-hazards.

~~A number of~~The successful ~~practices~~ examples described in this paper demonstrate that using UAVs for emergency investigation of single geo-hazards~~,~~ can ~~not only~~ greatly reduce the time, ~~strength~~ intensity and risks ~~of~~ associated with ~~the~~ on-site work~~, but also~~ and provide valuable high-accuracy and~~,~~ high-definition ~~valuable~~ information ~~to well~~that supports the development of ~~emergency treatment~~emergency responses.

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