Simulation of Blast Profiles and Fragmentation Analysis for Optimized, Safer Mining Operations Using Advanced Drone Technology

Abhay P[1], Akasha[2], Bhanuprakash[3], Bhuvan M S[4], Prof. Nataraja N[5]
[1,2,3,4]*Dept. of Electronics and Communication Eng. Atria Institute of Technology, Bengaluru, India*
[5]*Project Guide, Dept. of Electronics and Communication Engg., Atria Institute of Technology, Bengaluru, India*

***Abstract*— The size distribution of blasted rock affects loading, hauling and crusher-feed performance, yet conventional assessment often requires personnel to approach the muck pile. This paper describes a work-in-progress drone-assisted workflow for post-blast fragmentation assessment: a multirotor UAV with an ESP32-CAM imaging module and a bespoke 3 mm acrylic camera mount collects images of the rock face or muck pile and WipFrag 4 provides an estimate of the visible fragment-size distribution, summarized by D50 and D80. We describe the system architecture, the electronics block diagram, the acrylic mount design and the image-analysis procedure, and explicitly state its limitations. The drone assembly and electronics integration are complete. Camera integration, flight testing, photogrammetric 3D modeling and WipFrag analysis of project's own imagery remain to be done. No measured fragmentation results or safety/efficiency improvements are claimed. Future work is identified as blast-profile simulation and machine learning optimization.**

***Index Terms*— Unmanned aerial vehicle (UAV), rock fragmentation, WipFrag, muck pile, image analysis, photogrammetry, mining.**

I. INTRODUCTION

Blasting is the principal rock-breaking technique in open-pit mining and quarrying operations. The efficiency of the excavators, loading of the haul trucks, and crushing operations are influenced by the size distribution generated as a result; a muck pile that contains many larger blocks needs to be subjected to further breaking prior to processing. A large, irregular, or hazardous muck pile makes field assessment difficult.

A UAV can capture such imagery safely from a standoff distance, and overlapping aerial imagery is able to be processed through Structure from Motion (SfM) photogrammetry to build a 3D surface model [1]. Software for image analysis, like WipFrag, will estimate the fragment size distribution from a single photograph [2]. The current project aims to combine these two concepts.

The paper is intentionally constrained to serve as a report on an engineering prototype. Contributions made by this paper include: (i) a design of a drone platform to image a rock pile (III); (ii) an acrylic camera holder for use on the platform; (iii) a detailed process of conducting WipFrag 4 analysis together with data that should be collected during the experiment (IV); and (iv) project status and limitations (V-VI). The acrylic components are custom-made for the project; novelty of such designs is not claimed.

A. Problem Statement

The estimation of blast parameters is done through empirical formulae and observations. The main aim of this research project is to develop a repeatable method to take pictures of the rock faces and muck piles for the analysis of fragments sizes that can be further used in modeling of the blast profile.

B. Aim and Objectives

The idea is to design a drone-based methodology for documenting blast profile and analyzing the blast fragments which would lead to safer mining. Objectives are to:

- take aerial pictures of rock faces or muck piles using a UAV equipped with a camera;

- create three-dimensional surface or terrain models out of overlapping images through SfM photogrammetry, when possible;
- estimate the fragment size distribution of the muck-pile image using WipFrag 4;
- simulate blast profiles (burden, spacing, stemming, explosive shape) when all data needed for that are gathered; and
- apply machine learning optimisation only when a data set of blast parameters versus measurements of fragment size distribution becomes available.

II. RELATED WORK

UAVs in blasting design and safety. Pyra and Żołądek have employed a UAV and photogrammetry to construct 3D models of bench face in basalt quarry for burden analysis and correction of blast hole design; they found that UAV-based approach can reduce the fly rock distance in the area of interest by an average of 42%; this was estimated based on photographic and video documentation rather than controlled experiments [3]. Shrivastava explains the usage of UAV in the field of mining [4]. Aruna et al. have proposed IoT-enabled ground vibration monitoring with machine learning in surface blasting operations [5].

Fragmentation and muck-pile prediction. In the research by Gebretsadik et al., machine learning is used for rock fragmentation assessment in my blasting [6]. In the study conducted by Chandrahas et al., a data-driven algorithm based on UAV images and machine learning is proposed to predict muck pile parameters in the jointed overburden bench [7]. It can be seen that both UAV images and machine learning approaches have been explored in the studies, and this work does not duplicate these two approaches.

Photogrammetry. SfM photogrammetry is described as an inexpensive and efficient method in geosciences by Westoby et al., and the sensitivity of results to image acquisition and control is explained [1].

Limitations of image analysis. 2-D image-based techniques measure only the surface of the pile and are sensitive to issues such as scaling, lighting conditions, perspective distortion, fragment overlay and segmentation problems. Quantitative advantages stated in the literature are site-specific and method-dependent and do not apply to this research.

III. PROPOSED SYSTEM

A. Overall Workflow

Workflow (see Fig. 1) consists of preparing the UAV and camera, taking images of rock faces or muck piles using known scales for reference, transferring them to a computer where they are analyzed using WipFrag 4, and interpreting the obtained size distribution along with its limitations.

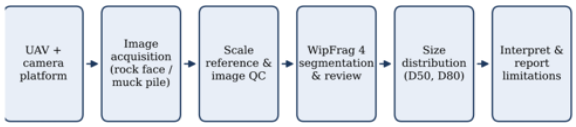


Fig. 1. Proposed UAV-assisted fragmentation-assessment workflow.

B. Drone Platform and Electronics

The platform consists of an electrically powered multirotor with its electrical components depicted in Fig. 2. The 3S LiPo battery powers the electronic speed control (ESC) and brushless motors, while the battery eliminator circuit (BEC) delivers regulated electricity to the flight controller and camera. The camera unit comprises an ESP32-CAM module that has a micro-SD card slot and transmits data via the UART communication channel; telemetry serves as a radio connection between the drone and the ground. From the review of the project progress, the assembly of the drone is complete.

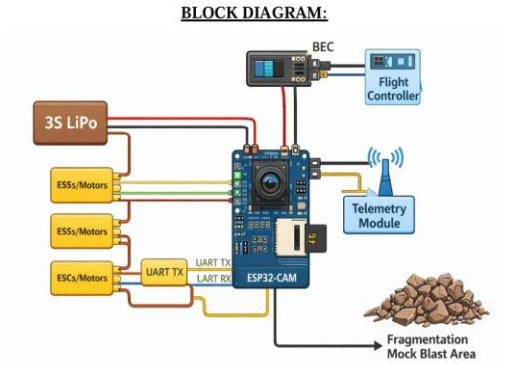


Fig. 2. Block diagram of the UAV electronics: 3S LiPo supply, ESCs/motors, BEC, flight controller, telemetry module and ESP32-CAM imaging unit.

C. Acrylic Camera Mount

Camera mount made from 3 mm acrylic was constructed (Fig. 3). It is comprised of one base plate (30 mm × 26 mm, four Ø3 mm holes), two side plates,

and an optional front plate, secured with M3 screws. This design provides a possibility of adjusting the tilt of the camera from 0° to 45°, making use of the existing holes on the top plate of the F450 class frame without any modification. Potential issues which should be inspected prior to flying include the following:

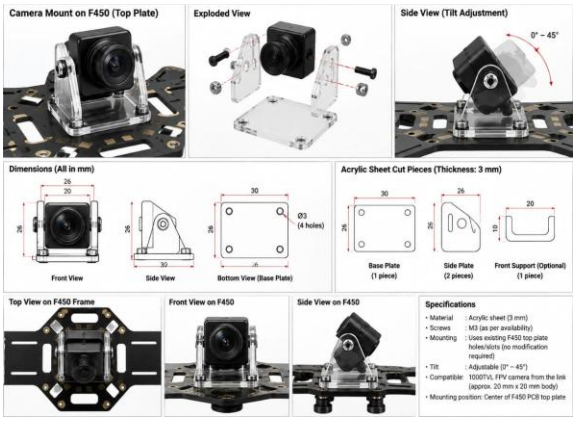


Fig. 3. Acrylic camera-mount design: assembled and exploded views, tilt range, dimensions in mm and cut pieces (3 mm acrylic).

The design of an acrylic flight controller mounting plate (75 mm x 75 mm), 2 mm thick with a stack size of 30.5 mm x 30.5 mm and a solid model for use with Pixhawk/APM controllers is also underway. An acrylic top cover for the airframe is also in development stage. There are no claims of any protection or improvement in flight performance since there were no testings performed.

D. Software

Image-based Fragmentation analysis uses WipFrag 4. The project synopsis further lists Agisoft Metashape (SfM point cloud and DEM), CloudCompare, GIS tools, and blast design tools such as JKSimBlast among other software for later stages.

IV. METHODOLOGY

A. Image Acquisition and Selection

There is no use of an explosive charge in this project. Therefore, in the analysis phase, we would have (a) images of an organized stone heap along with a scale bar captured by the UAV and by using ground imagery from repeatable view-points, and, if necessary, (b) sample mining images which are to be clearly marked as being external and not taken by the UAV. Images selected need to have a well-defined surface area with plenty of fragments, enough resolution for the demarcation of boundaries, no blurring and shadow effect, a scale bar in the same plane as that of the fragments, and from a position where there is less perspective distortion.

B. WipFrag 4 Analysis Procedure

For each image: (1) open the image in WipFrag 4 software; (2) set the scale from the reference object; (3) set the segmentation and boundaries parameters; (4) check the results of fragment detection for mistakes, like adjacent stones being combined, one stone divided into several pieces, shadow mistaken for a boundary etc.; (5) perform the analysis; (6) note down the cumulative size distribution and characteristic sizes D50 and D80 - sizes below which 50% and 80% of material falls respectively; (7) save the original image, overlay, output table and screenshots. In the log for each image the following information is recorded: image id and name, type (captured by a drone/ground equipment/externally), calibration type used, WipFrag version and parameters, manual segmentation editing.

C. Planned Extensions

The overlapping UAV images can be analyzed using photogrammetric SfM techniques for reconstruction of the rock-face/terrain geometry [1], specifying software used, image overlap, scale/control method, and outputs. The simulation of the blast profile and development of machine-learning models are for future research and will require the validated dataset.

V. DISCUSSION AND LIMITATIONS

However, there is a need to confirm the usefulness of the workflow through a trial run that involves use of drone acquired images and image analysis software to determine visible fragments size estimates. Some of the constraints include:

- Surface only bias: the parts that are not covered on the surface cannot be captured.
- Scale calibration: pixel size cannot be converted to real physical size in absence of scale.
- Spatial distortion and occlusion: far away and occluded fragments have more measurement errors.

- Segmentation error: two neighboring rocks may be misclassified together while one rock may be segmented into several pieces.
- Image source: third party images cannot show how good is the performance of the UAV used for the project.
- Lack of proof of concept: in absence of the actual blast, burden/spacing settings and blast fragmentation cannot be confirmed, hence no reduction in oversize, improvement in crusher feed, cost reduction and increased safety is shown.

VI. CONCLUSION AND FUTURE WORK

A UAV-based process for the rock-fragmentation assessment based on images was introduced in this paper, with details about the electronic configuration of the UAV, a camera holder made of acrylic material, and a WipFrag 4 analysis technique. The system has not been built yet, and the imaging and analysis processes are yet to be done, hence there have been no conclusions from any real-world implementation. Upcoming work includes the completion of the camera mounting and the flights, analysis of the collected images of the project scaled with accuracy, repetition test of the camera mount, 3D modeling through SfM, and only after that, blast profile simulation and optimization.

ACKNOWLEDGMENT

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