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# A practical application of photogrammetry to performing rib characterization measurements in an underground coal mine using a DSLR camera

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ABSTRACT

Understanding coal mine rib behavior is important for inferring pillar loading conditions as well as ensuring the safety of miners who are regularly exposed to ribs. Due to the variability in the geometry of underground openings and ground behavior, point measurements often fail to capture the true movement of mine workings. Photogrammetry is a potentially fast, cheap, and precise supplemental measurement tool in comparison to extensometers, tape measures, or laser range meters, but its application in underground coal has been limited. The practical use of photogrammetry was tested at the Safety Research Coal Mine, National Institute for Occupational Safety and Health (NIOSH). A commercially available, digital single-lens reflex (DSLR) camera was used to perform the photogrammetric surveys for the experiment. Several experiments were performed using different lighting conditions, distances to subject, camera settings, and photograph overlaps, with results summarized as follows: the lighting method was found to be insignificant if the scene was appropriately illuminated. It was found that the distance to the subject has a minimal impact on result accuracy, and that camera settings have a significant impact on the photogrammetric quality of images. An increasing photograph resolution was preferable when measuring plane orientations; otherwise a high point cloud density would likely be excessive. Focal ratio (F-stop) changes affect the depth of field and image quality in situations where multiple angles are necessary to survey cleat orientations. Photograph overlap is very important to proper three-dimensional reconstruction, and at least 60% overlap between photograph pairs is ideal to avoid unnecessary post-processing. The suggestions and guidelines proposed are designed to increase the quality of photogrammetry inputs and outputs as well as minimize processing time, and serve as a starting point for an underground coal photogrammetry study.



## 1. Introduction

The stability of underground mine ribs has been a safety concern for underground coal mines for decades. Unfortunately, the average rib fatality rate has been about 1.3 per year between 1996 and 2013 [1]. In an effort to better understand coal rib behavior, photogrammetry is being investigated in this study as a measurement tool for surveying ribs in an underground coal mine environment.

Photogrammetry is a method of image measurement used to derive the shape of an object as determined from multiple photographs. Photographs themselves, being two-dimensional representations of three-dimensional space, have an inherent loss of information, but measurements can be inferred by analyzing the shape of an object with the relative camera positions [2]. This paper specifically deals with close-range digital photogrammetry (CRDP), which is typically limited to objects or scenes less than 100 m from the camera [3]. In recent years, the practice of photogrammetry has seen increased applications to research in underground mines, such as work characterizing fracture networks and establishing a pillar rating system, rock mass and support monitoring, and an assessment of pillar spalling in unstable limestone mine workings [4–9].

The use of this technology in underground coal mines has been severely limited, in large part due to the lack of Mine Safety and Health Administration (MSHA) approved options for photography equipment in the potentially explosive atmosphere. Additionally, the visible features in an underground coal mine are markedly different from those of other underground mines. The goal of this

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study is to determine what photogrammetry methodology, camera settings, and lighting scenario will work in an underground coal mine environment, considering the potential equipment limitations.

## 2. Experiment methodology

Three sites were selected at the NIOSH Safety Research Coal Mine, shown in Fig. 1, to test the best methods for applying photogrammetry as a measurement tool for rib characterization in underground coal mines. The mine entries are approximately 4.3 m wide and average 2 m in height. Several objectives were identified: determining cleat orientation and spacing, measuring rib displacement, and performing routine length measurements. Ideally the measurements could be performed quickly and easily, so the experiments tested methods of photography that vary in data collection time and complexity.

A Nikon D5500 DSLR camera was used with an AF-S NIKKOR 35 mm 1:1.8G lens. This camera is not purposefully configured for photogrammetry. The following camera settings were common to all the experiments: fine image quality, 6000 × 4000 resolution, automatic bracketing, HDR off, automatic active d-lighting, auto white balance, standard picture control, automatic focus, auto-area (AF) mode, point metering, 0 flash compensation, and 0 exposure compensation. The settings that were changed on an experiment-specific basis, to compensate for lighting and depth of field changes, are detailed in their respective sections.

Two lighting systems were independently investigated: the camera's onboard flash and an external LED lighting system. The LED lighting system is currently under development by NIOSH for use in underground coal environments and consists of twelve small LEDs mounted to a singular circular frame with an attached handle. The LEDs are angled in a way to evenly distribute light across a coal rib. The even distribution of light allows the lighting system to be moved along with the camera without significantly changing the rib's appearance. When necessary, cap lamp lighting was also used to allow the camera to automatically focus.

### 2.1. Site A

The purpose of the Site A (Fig. 1) experiments was to obtain enough detail on a rib to measure cleat spacing and orientation. This was attempted using both the onboard flash for the Nikon camera and the external NIOSH LED lighting system. The camera settings used for each experiment at this location are shown in Table 1. All the reference objects used in these experiments are shown in Fig. 2.

Using the Nikon's onboard flash or an LED lighting system, hereafter called the LED lighting or simply LED, photographs were taken at varying heights and angles surrounding the corner of a pillar (Fig. 3). The perpendicular photographs were taken approximately 3 m from the rib, while the high-angle photographs were taken about 1.5 m from the rib. An area of rib visible in several of these photographs was selected for a measurement comparison between photogrammetry and traditional methods using six different features, labeled as M1 through M6. Most of these photographs were taken at an orientation perpendicular to the rib surface. However, several were taken at high angles-of-incidence to better capture the depth of the rib. These high angle-of-incidence photographs were taken at different F-stops to compare the changing depth of field focus. The shutter speed and ISO were adjusted to account for this change in light sensitivity. Additionally, a set of photographs was collected using an intentionally more haphazard approach without evenly spaced or angled photographs, with no regard for overlap, and using the camera's automatic settings. This was done to emulate a casual approach where the camera operator is minimally instructed on an ideal photogrammetry methodology. The regimented sets of photographs required

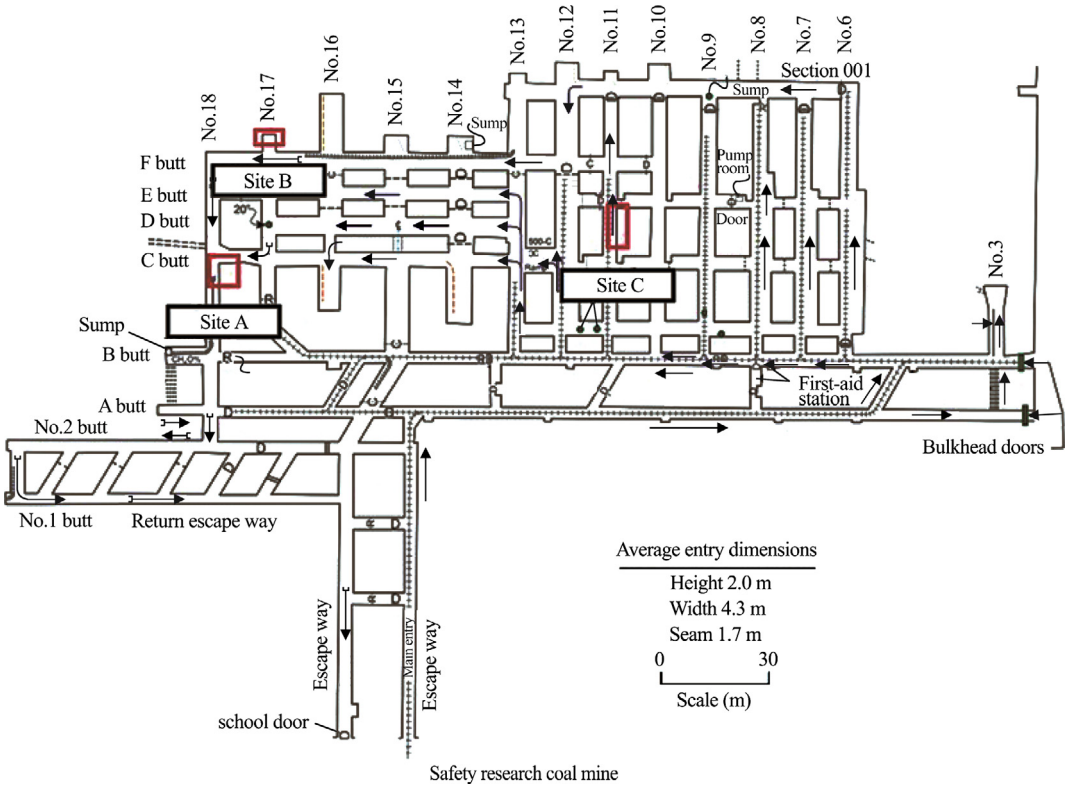


**Fig. 1.** Study sites at the safety research coal mine.