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3-D laser imaging of drill core for fracture detection and Rock Quality Designation

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ABSTRACT

The Rock Quality Designation (RQD) is a widely used parameter in empirical methods of estimating rock mass strength. This proof of concept research is a step toward the semi-automatic computation of the RQD and is based on 3-D imaging procedures and algorithms to detect fractures in drill core. The images were acquired with a triangulation-based 3-D laser digitizer. Each image file is a point cloud of spatially referenced measurements in Cartesian space. Variations in the *z*-coordinate (digitizer-to-target distance) were used to detect fractures in profile. Natural fractures were distinguished from mechanical breaks by measuring the angle, and quantifying the roughness, of the fracture trace. The algorithms use a binary centerline profile to measure intact lengths of core for the RQD calculation. This 3-D approach measures changes in the core surface, not intensity features and shadows as with 2-D photographs. Limitations arise when there is no detectable change in the *z*-coordinate.

1. Introduction

1.1. Rock Quality Designation (RQD)

Fractures affect rock mass strength, and therefore collection of fracture data is fundamental in any geomechanical design project. One source of fracture data is drill core. The Rock Quality Designation (RQD) – the percentage of unbroken core fragments longer than 10 cm (L_c) over the total length of a core run (L_t) – is a key indicator used in the rock mass strength assessment process [1]. These percentages correspond to the qualitative descriptions of rock mass quality, shown in Table 1. The importance of the RQD is demonstrated by its use as a parameter in the widely employed Rock Mass Rating (RMR) [2–6] system and the Rock Quality Tunneling Index (Q-system) [7]. The RQD equation is as follows:

$$\mathrm{RQD}\ (\%) = \sum (L_c/L_t) \times 100\% \quad (1)$$

Reliably determining the RQD, however, is a challenge. Natural fractures that are the result of geological processes must be distinguished from mechanical breaks in the core caused by drilling [8–11]. The properties that characterize natural fractures (weathered/altered, smooth breakage surface) and mechanical breaks (fresh, rough, high-angle breakage surface) are few and often subtle [8]. Illustrated in Fig. 1 is an example of a natural fracture and a mechanical break. The fractures shown in Fig. 1 are end members; in practice, many fractures have ambiguous properties and their origin is difficult to reliably discriminate.

In most cases, mine professionals have limited time to process core. For example, Hadjigeorgiou [12] writes that at one mine, 10–15 core boxes are placed on the ground and the geologist "eyeballs" the RQD by quick visual inspection. This is common practice at many mines. Storing core requires a significant amount of space. Furthermore, core that contains ore is typically split for assay, rendering future RQD measurement impossible. Core considered waste material is often discarded, also preventing future inspection or logging. A new approach is needed to improve observation of fractures in drill core and the measurement of the RQD. Image analysis of core avoids these issues. It is inexpensive to store image data and it can be accessed as many times as needed in the future.

1.2. 2-D image analysis

Over the past few decades, edge detectors such as Sobel [13] and Canny [14] and line detectors [13,15–18] have been developed and successfully applied to 2-D images (digital or scanned conventional photographs) to identify a variety of linear features, including arteries in medical scans [17], roads in aerial photographs [15,17], joint traces on rock faces [16,18–21] and fractures in drill core [22,23].

Fracture traces are detected by abrupt changes in pixel intensity values – light pixels correspond to high intensity readings, whereas the low intensity values represent dark pixels. Fractures in core

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appear as dark lines or curves cross-cutting the lighter intact surface. The fundamental assumption of these 2-D methods is that pixel intensity corresponds to surface elevation [18]. This assumption may not be valid in every case. Intensity variations are a function of light and shadow; they are not a physical property of the rock mass or drill core. As such, this approach is highly dependent on ambient lighting conditions. Improper lighting can cause shadows and glare that degrade the performance of an image-processing algorithm [21]. Dark colored core may lack sufficient contrast with fractures, which makes the detection of these discontinuities problematic. Fractures are not the only features identified by edge or line detection algorithms; intensity changes may also be due to rock texture, mineral veins or sedimentary beds [19].

1.3. Research objectives

The problems associated with rock texture and lighting conditions are essentially eliminated with 3-D imaging [24]. In recent years, 3-D laser imaging has been applied to map rock mass discontinuities [24–32]. These studies have primarily focused on joint orientation and surface roughness of medium to large rock masses, such as mine tunnels and road cuts. Fracture detection in drill core for RQD calculation is a novel application of high-resolution 3-D imaging [33,34]. In this paper, we report on semi-automatic imaging procedures and algorithms to locate, measure and count fractures, distinguish natural fractures from mechanical breaks, and calculate the RQD.

2. Methods

2.1. Instrumentation

The 3-D images were obtained with a Konica Minolta VIVID 9i non-contact laser digitizer. This triangulation-based digitizer uses the light-stripe method to acquire data. A laser beam is emitted through a cylindrical lens onto a galvano mirror. The motion of the mirror causes the light stripe to pass over the target from top to bottom. The light is reflected from the target, focused by the receiving lens, and received by the charge-coupled device (CCD) detector. The light information received by the CCD is converted to Cartesian coordinates by triangulation. This process generates the 3-D point cloud data. A 640×460 pixel digital color photograph is also obtained at the same time.

Table 1
RQD and the associated rock mass quality [1].

RQD (%)	Rock Mass Quality
<25	Very poor
25–50	Poor
50–75	Fair
75–90	Good
90–100	Excellent

2.2. Digitizer configuration

Two digitizer configurations are used. For fracture detection and the computation of the RQD, the core is scanned in the core box. This will be referred to as the core box configuration. The core is scanned in the box to mimic real-world core logging conditions. As illustrated in Fig. 2, the digitizer is mounted on a tripod, angled at 90° from vertical. The front of the enclosure, with the laser-emitting window and light-receiving lens, is parallel to the target core box. Parallel orientation is needed so that the emitted laser is projected onto the target at normal incidence, thereby minimizing perspective effects.

The accuracy is ± 0.40 mm using the wide lens (focal distance: 8 mm) at a distance of 0.9 m. The wide-lens allows the greatest digitizer-to-target distance – more of the target can be captured in one image. Even so, the entire length of the core box does not fit in a single image. With a field of view angle of roughly 35° and a digitizer-to-target distance of approximately 0.9 m, the size of the imaged area is about 450 mm $\times$ 600 mm. Thus, a 1.5 m core box must to be scanned in three sections, each section at least 0.5 m in length.

With the second configuration, for fracture characterization (i.e., natural versus mechanical), the core is placed on a turntable and scanned. This will be referred to as the turntable configuration. The accuracy is ± 0.05 mm using the tele lens (focal distance: 25 mm) at a distance of 0.6 m. As shown in Fig. 3, the tripod-mounted digitizer is angled so that the emitted laser beam is approximately normal to the target core axis. The field of view angle is roughly 14°, digitizer-to-target distance is approximately 0.6 m and the size of the imaged area is about 70 mm $\times$ 125 mm.

2.3. Image properties

Each image file is a point cloud of spatially referenced measurements in Cartesian space – x is parallel to the long axis of the

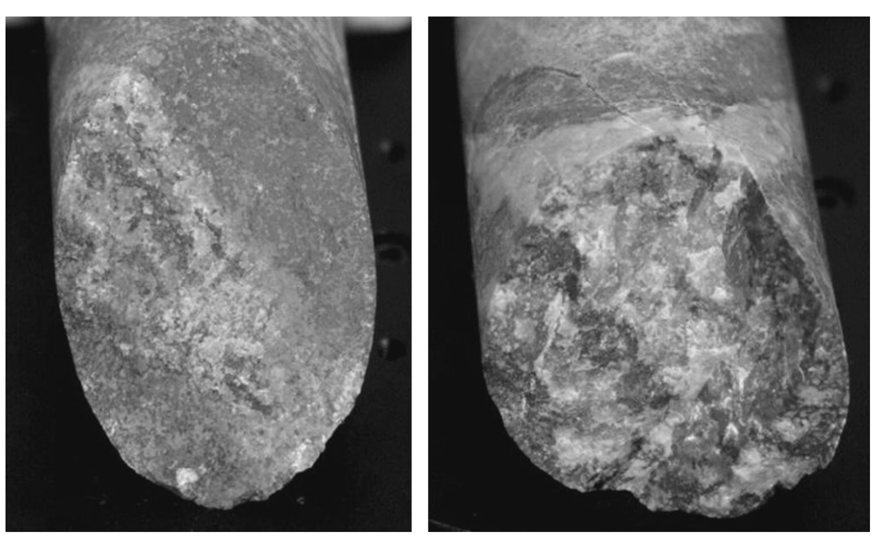

Fig. 1. Natural fracture (left) and a mechanical break (right). Core diameter is 47.6 mm.