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Study on the Influence of Borehole Conditions on Panoramic Side-View Borehole Images in Underground Coal Mines

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ABSTRACT

Borehole scoping has been widely used in the U.S. underground coal mines as a method for geologic mapping and stability analysis because it is very useful for identifying rock types, voids, fractures, and formation boundaries through the direct observation of the borehole wall. An image stitching technique was proposed to generate panoramic borehole images from side-view borescopes in a previous study. However, the generation of panoramic borehole images can be affected by the borehole condition because the image stitching process highly depends on the key point detection and matching. The presence of dust and water could have a significant influence on the detection of key points. In this study, the influence of borehole conditions on panoramic borehole images was studied from the success of image stitching and the visibility of geologic features and lithology changes. Borehole videos recorded at different times, when the same borehole was freshly drilled, freshly washed with water and 12 days after washing, were processed with the proposed technique. The comparison of the stitched images shows that the presence of dust has minimal influence on the image stitching process but shows significant negative effects on the visualization of geologic feature and lithology change. In addition, the presence of water can significantly hinder the image stitching process, which in turn helps in identifying lithology change. Borehole scoping aids in identifying and mitigating hazardous conditions in underground mines, and this study provides preliminary inputs into identifying optimum borehole conditions for geologic mapping with panoramic borehole images.

INTRODUCTION

Accurate characterization of the roof lithology within the bolting horizon is very important for effective roof support design. Borescoping has been widely used in the U.S. underground coal mines as a method for geologic mapping and stability analysis. It provides an efficient and practical method to directly observe the in-situ structures of borehole wall through the optical imaging technique. Borehole scoping can provide detailed visual information about the lithology, structure, and any potential weak spots such as faults, bedding planes, or inclusions, which is essential for roof characterization and roof support design in underground coal mines (Peng 2005; Iannacchione et al. 2006a, b; Bahrampour et al. 2015; Liu et al. 2018) Also, borehole scoping can be used to assess the stability of the surrounding rock strata. By observing the formation of new fractures and the opening of bedding planes, borehole scoping helps in identifying potential instability that could pose safety risks during mining operations.

In U.S. coal mining industry, a borehole scoping system typically includes a video scope, a water pump, and support poles. The water pump is used to wash boreholes and remove the dust covering the borehole wall. The tip of the video scope is attached to one support pole and is pushed up by the support poles one by one. The depth is normally marked on the support poles with a certain interval, and as a result, they need to be connected following a specific order. When scoping a borehole in underground coal mines, it is important to have an experienced geologist at the site for identifying and documenting the geologic features or lithology changes and the corresponding depth.

Instead of conducting borehole scoping underground with an experienced geologist, one panoramic image can be generated from a recorded borehole video to visualize the in-situ structures of borehole walls. Any personnel can record the borescope video, and a geologist can later review the borehole after image stitching. The file can be sent to a geologist remotely, allowing them to provide quick feedback even if they are not present at the mine site. There are mainly two methods to form panoramic borehole images, namely seamless stitching approach and scan line approach (Wang et al. 2006). The former method stitches the video frames with a certain overlapped region to form a panoramic image with high accuracy, which requires a large amount of data to be processed. The latter method uses a designated circle as a scan line to collect the data on the circle and the collected scan lines are heaped up along the depth direction to form a borehole image. Due to the development of image processing techniques and computer sciences, it becomes less difficult to conduct image stitching, the former method starts to draw attention and research interests (Niu et al. 2011; Cao et al. 2018; Deng et al. 2019, 2023; Zou and Song 2021; Zou et al. 2021b, a) geological structure detection is crucial to the engineering design and implementation. One of the most commonly used method is to acquire the borehole videos by Axial View Panoramic Borehole Televiewer (APBT. Another advantage of generating panoramic borehole images is quantitative evaluation. Quantitative measurement can be conducted for the roof strata within the borehole horizon after obtaining the panoramic borehole images, and there are wide applications of borehole images in the literature. Panoramic borehole images were used to evaluate the rock mass integrity by avoiding the mechanical disturbance on cores during the drilling process (Wang et al. 2006). The structural plane parameters, such as the central position, orientation and dip angle, and the morphological features of structural planes in the form of joint roughness coefficient (JRC) can also be extracted from borehole images (Wang et al. 2017a; Zou et al. 2020). The in-situ stress can be estimated from the recorded change in borehole shape or borehole breakout in borehole images (Wang et al. 2018; Zou et al. 2018; Han et al. 2020). The porosity distribution in coral reefs was also evaluated through high-precision borehole images (Wang et al. 2017b). All of these available literatures have been focusing on the forward-view borehole cameras, which captures borehole images directly ahead of the camera. However, the U.S. coal industry has been mainly using the side-view borescopes, and there is no available study for the side-view borescopes.

In a previous study, the authors developed the methodology to generate panoramic borehole images by stitching the frames of borehole videos recorded with a side-view borescope, and the video frames recorded a few weeks after washing were successfully stitched to visualize the borehole (Xue et al. 2024). However, the image stitching process and roof lithology identification can be significantly affected by the borehole wall condition. If a borehole is freshly drilled, the wall is normally covered with rock dust, making it difficult to identify the geologic feature and lithology change. With freshly washed boreholes, water remains on the wall and reflects light, making it hard to see anything on the wall. Comparing with these two conditions, the washed and dried borehole wall was originally considered as the ideal condition for borehole scoping. In this study, the influence of borehole wall conditions on the panoramic borehole images was investigated. The developed methodology for stitching side-view borehole video frames was first briefly described. The method was then used to generate panoramic borehole images from the videos recorded under three different borehole wall conditions. Their influence was compared based on the success of borehole image stitching and the identification of geologic features and lithology change.

METHODOLOGY FOR GENERATING PANORAMIC BOREHOLE IMAGES

The process for stitching a borehole video is summarized in the flowchart shown in Figure 1. It normally includes image acquisition and preprocess, key point detection, key point matching and filtering, offset calculation, image alignment, and image blending, if necessary.

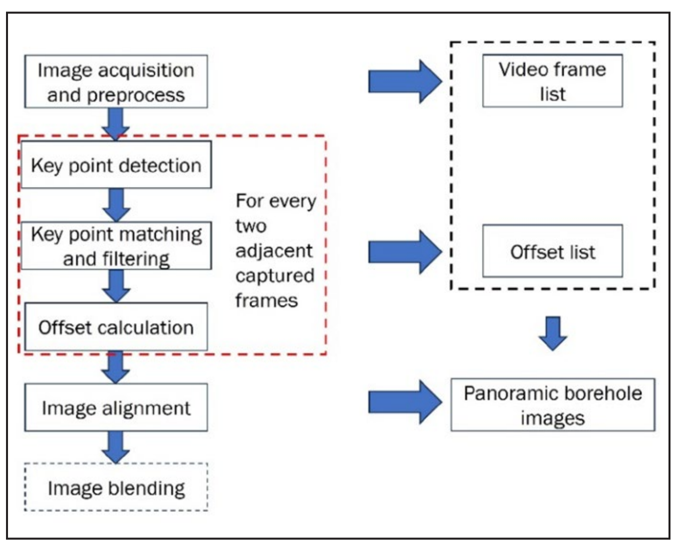

Figure 1. Flowchart of image stitching process with a recorded borehole video

Image acquisition is the process of capturing a set of overlapped video frames from a recorded borehole video and image preprocessing techniques, such as grayscale conversion and histogram equalization, can be carried out to improve the key point detection. The video frames are captured, preprocessed, and stored as a list.

The next step is to estimate the homography between every two adjacent frames in the video frame list by detecting the key points in each frame and matching the key points and estimating the geometric transformation between every two adjacent frames. The process of key point detection uses a feature detection algorithm to identify distinctive key points as features and extracts the associated descriptors. Different algorithms, e.g., Scale-Invariant Feature Transform (SIFT), Speeded-Up Robust Features (SURF), Oriented FAST and Rotated BRIEF (ORB), have been used for feature detection in borehole images (Ma et al. 2019; Zou et al. 2021a; Deng et al. 2023)it is often highly desirable to observe images of whole microscopic sections with high resolution. So that micrograph stitching is an important technology to produce a panorama or larger image by combining multiple images with overlapping areas, while retaining microscopic resolution. However, due to high complexity and variety of microstructure, most traditional methods could not balance speed and accuracy of stitching strategy. To overcome this problem, we develop a method named very fast sequential micrograph stitching (VFSMS. The ORB algorithm was found to have a good performance in efficiency and accuracy for this study. Examples of detected key points are present in Figure 2. For each detected key point, one descriptor can be extracted as a vector to represent the local appearance around each detected key points, making it possible to match key points across different images.

The goal of key point matching is to find correspondence between the key points detected in two adjacent images by matching the descriptors from one image to the descriptors from another image. However, many key points may have similar descriptors, especially in the regions with repetitive patterns, and as a result, a key point in one image may have multiple potential matches in another one, as shown in Figure 3 where the potentially matched key points are connected. It is essential to filter out ambiguous matches to ensure robust and accurate matching. This is normally done with a ratio test. Figure 4 shows the matched key points after filtering with a ratio of 0.75, and significant improvements in the overall accuracy of the feature matching with the ratio test can be observed.

Offset calculation is the process to find the transformation between two adjacent frames based on the matched key points. The transformations between two images include translations, rotation, scaling, shearing, and perspective transformations. However, if a borescope moves in a borehole and the distance from the borehole wall is maintained constant, the only transformation involved in the recording process is translation when the borescope moves vertically and rotates horizontally, presenting a considerable scanning problem (Ma et al. 2019)it is often highly desirable to observe images of whole microscopic sections with high resolution. So that micrograph stitching is an important technology to produce a panorama or larger image by combining multiple images with overlapping areas, while retaining microscopic resolution. However, due to high

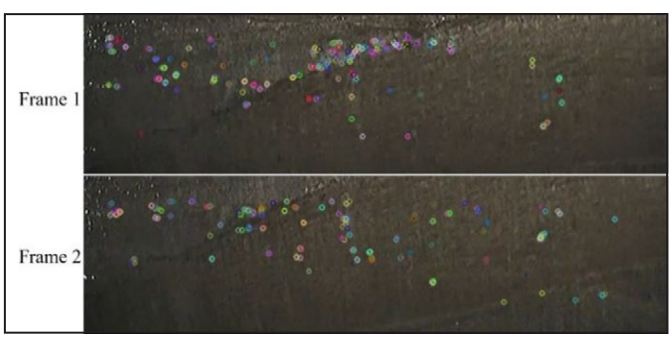

Figure 2. Key points that were detected with the ORB algorithm

Figure 3. All matches between the detected key points in two adjacent images

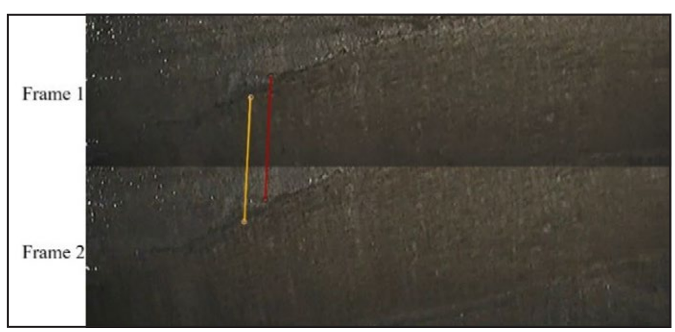

Figure 4. Filtered matches of key points between two images

complexity and variety of microstructure, most traditional methods could not balance speed and accuracy of stitching strategy. To overcome this problem, we develop a method named very fast sequential micrograph stitching (VFSMS. Thus, the offset along the vertical and horizontal directions as shown in Figure 5 can be calculated from the matched key points to represent the transformation between two adjacent borehole images. Starting from the first frame, these offset values can be calculated one by one for the following sequential frames until the last frame and are stored as an offset list.

Image alignment involve aligning one image to another and then warping the images onto the final canvas to create a panoramic borehole image. After obtaining the list of video frame and offset, starting from the first one, the frames in the video frame list can be aligned one by one based on the calculated offset values in the offset list to generate the panoramic borehole image. If necessary, image blending can be conducted to create a seamless transition between the overlapped regions to ensure the visual consistency of the stitched images without noticeable seams.

However, the sequential image stitching process may fail at some point. When the algorithms cannot detect enough key points or cannot find good matches, the offset between two adjacent frames cannot be estimated, leading to the failure of the image stitching process. In order to continue the stitching process, the new frame is moved to the bottom of the previous frame and is further moved down with a gap to show the location of stitching failure. As a result, a gap in the stitched borehole image indicates the disconnection of the following image segment from the previously stitched segment.

Figure 5. Offset calculation between two adjacent images

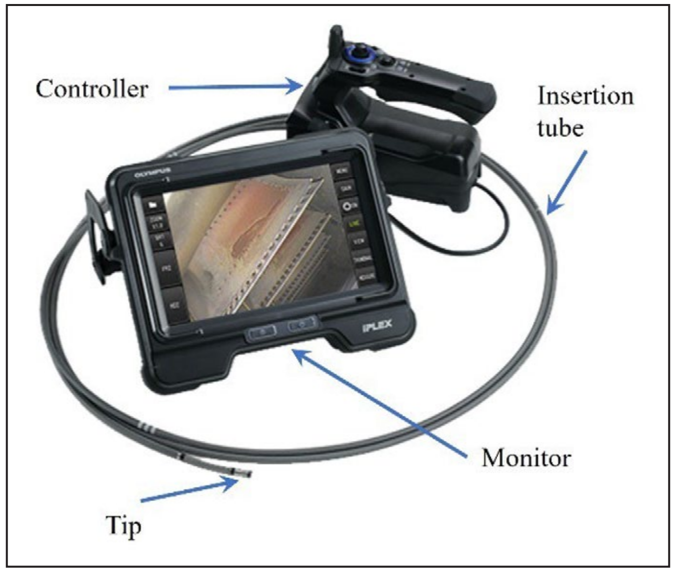

Figure 6. The side-view video scope used in this study

BOREHOLE VIDEOS WITH DIFFERENT BOREHOLE CONDITIONS

It can be found from the image stitching process in Section 2 that the detection and matching of key points between overlapped video frames are crucial for the sequential image stitching. The stitching process would fail if the algorithm cannot find enough key points in the borehole images or cannot find good matches for the key points in two adjacent video frames. The appearance of a borehole may vary with the wall condition. With a freshly drilled borehole, the wall is normally covered with rock dust. If a borehole is freshly washed, water remains on the wall and reflects light. These wall conditions can potentially affect the process of key point detection and matching and further affect the generation of panoramic borehole images. One objective of this study is to investigate the influence of borehole wall conditions through the performance of the image stitching methodology.

The same borehole was scoped three times under different conditions and three borehole videos were recorded for this study. As shown in Figure 6, the IPLEX GX video borescope from Olympus America was used (Olympus). The borehole was in the roof of a room-and-pillar mine in West Virginia, USA. The diameter of the borehole was 25.4 mm (1 inch). The depth of the borehole was measured to be 2.56 m with very limited roof deformation during the study period. The videos were recorded when the side-view borescope tip moved downward towards the roofline. The moving speed and orientation were maintained at a constant rate as much as possible during scoping. The first video was recorded on 12/6/2023, a few weeks after the development of the entry, and there were rock dust covering the borehole wall. The second video was recorded on 1/5/2024 after the borehole was freshly washed with water to remove the rock dust from the borehole wall. The third video was recorded on 1/17/2024, about 12 days after the washing when the borehole wall was assumed to be dry. The

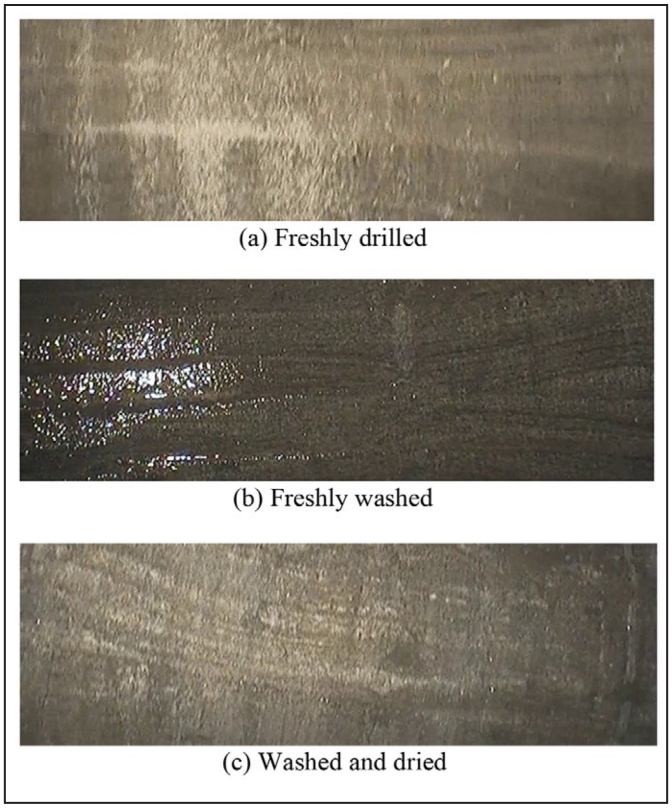

Figure 7. Borehole video frames under three different conditions

recorded videos were then processed with the image stitching algorithm, and comparisons were made based the image stitching performance and the visibility of geologic features and lithology change.

Examples of borehole video frames under three different conditions are shown in Figure 7. They were captured at the similar location within the borehole. However, the side-view borescope can only cover one side of the borehole, it is difficult to ensure that the scoping follows the same route and faces the same direction when recorded these three videos and minor differences may be observed. In general, it can be found that the presence of water or dust affects the appearance of borehole wall. The washed and dried borehole in Figure 7 (c) can be treated as the ground truth condition. Compared with Figure 7 (c), there are dusts covering the borehole wall in Figure 7 (a). Although the dusts cover the original key points on the borehole wall, there are areas that were not covered, and the dusts may create new key points to be detected and matched. Just from the image stitching point of view, it does not matter whether key points are on the true borehole wall or introduced from dusts. At the same time, Figure 7 (b) shows that the presence of water on the borehole wall causes reflection of the camera light on part of the borehole image. It potentially affects the observation of geologic features and introduces unrealistic key points. The problem with these introduced key points is that they can change with the movement of the camera light. Another problem is that the reflections can be easily blurred with a fast-moving borescope. All these problems can potentially lead to the presence and the increased number of stitching failures during the sequential image stitching with freshly washed boreholes. Although increasing the difficulties in stitching the borehole images, the presence of water makes the transition from one layer to another layer for the laminated shale clearer than the dried one if comparing Figure 7 (b) and (c).

RESULTS AND DISCUSSIONS

In this section, the image stitching algorithm was used to generate panoramic borehole images from the borehole videos recorded in the same borehole under three different conditions. The influence of borehole wall condition was compared from the success of image stitching process and the visibility of geologic features.

The Influence on Image Stitching Performance

One objective of the study was to investigate the influence of borehole wall conditions on the generation of panoramic borehole images. However, the sequential image stitching can also be affected by the borescope movement. The videos were recorded at different times, and there could be inconsistent borescope movements during the recordings. For example, one video could be recorded with constant and smooth movement, while the other was recorded with sudden movements at certain points. The ideal condition is to record the videos with consistent smooth movement and at a constant speed so that the borehole conditions could be the only affecting factor for comparison. However, the borescope movement is hard to be maintained manually, and as a result, the analysis of the influence of borehole conditions on the image stitching process was combined with the analysis of borescope movement.

The question is how to quantify the borescope movement when scoping a borehole. If the distance between the borescope and borehole wall is assumed to be constant, the area that one pixel covers on the borehole wall should be the same on the borehole images. If one borehole video can be sequentially stitched together to form a panoramic borehole image, the length of one pixel represented in the borehole can be approximately calculated by dividing the measured borehole depth with the total number of pixels along the borehole depth direction, which is the image height of the panoramic borehole image. After obtaining the dimension of area that one pixel covers on the borehole wall, the distance/location of one stitched frame from the borehole end can be approximated from the accumulative offset value from the first video frame, and the horizontal and vertical movement of this frame can be obtained from its offset values. In this way, the horizontal and vertical movement of the video frames, estimated from the corresponding offset values in pixels, can be marked at different locations along the scoped borehole, corresponding to frame location. This can help visualize the borescope movement when scoping a borehole where smooth movements with constant speed are expected. The borescope movement in vertical and horizontal directions for the three recorded borehole videos is presented in Figure 8.

It should be noted in Figure 8 that there are break points, representing the locations where the image stitching process failed. If the borehole video cannot be stitched together, multiple borehole image segments would be obtained with gaps, as can be seen in Figure 8, with a segment of the stitched borehole images with 4 break points. Instead of having small offset values along vertical and horizontal directions, the frame that cannot be stitched to the previous one is moved vertically to the bottom of the previous frame and is further moved down with a gap for visualization purposes. Under this circumstance, the borehole length that the panoramic borehole image covers should be longer than the borehole depth, which can be observed in the next section. The generated panoramic borehole images have a height varying from 70,000 to 80,000 pixels. The cropped image height was 250 pixels, and a gap of 10 pixels was used in this study. Compared with the image height, the influence of the extra pixels on the averaged pixel dimension can be negligible, and thus, even though there are extra pixels that resulted from the failure in the image stitching process, the borehole depth was averaged over the panoramic image height for the following calculation of video frame location and borescope movements in Figure 8. It must be mentioned that, due to the failure in the image stitching process, there were large spikes in the vertical movements in Figure 8 at the borehole locations marked with break points. Rather than true vertical movements, these are artificial movements from the image stitching process to demonstrate the break points and continue the following stitching process. They were removed from the plot. At the corresponding locations, break points were used to mark the failure in the image stitching process.

In Figure 8, the positive values mean downward movement in vertical direction and indicates the borescope rotates towards the right in horizontal movement. The negative values in vertical movement indicate the borescope moves up and left rotation in horizontal movement. It is

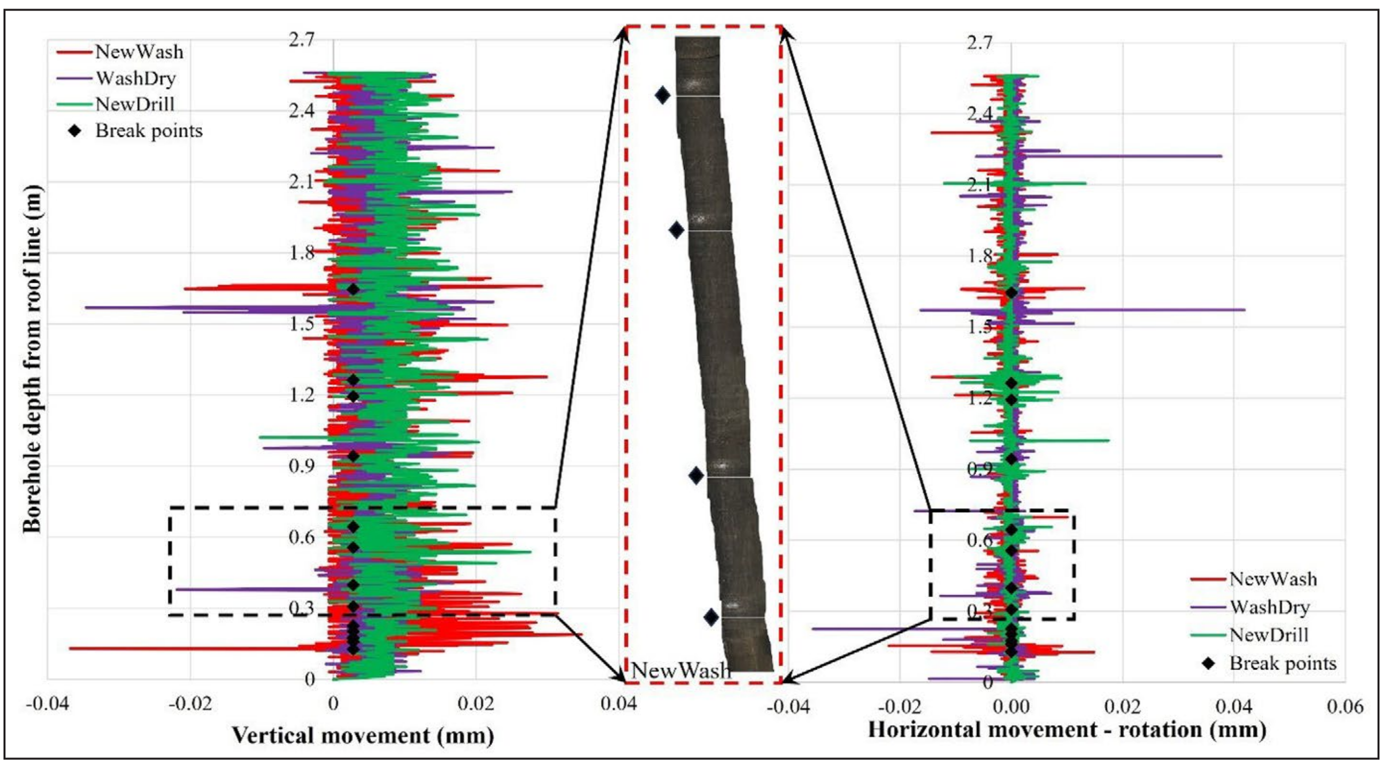

Figure 8. Comparisons of borescope movement during recording under three different conditions with a segment with four break points under freshly washed condition

always expected to move the borescope downwards with very limited horizontal movement. In such a way, the vertical movement will show a constant positive value, and the horizontal movement will have a value close to 0. However, it is difficult to achieve with manual control. It can be observed in Figure 8 that the borescope moved up and down and rotated left and right with some spikes indicating sudden and large movements. In general, as compared with the vertical movement, the horizontal movement is generally much smaller with a few spikes. The top end of a support pole has a slightly larger diameter than the bottom end so that two support poles can be connected by inserting the upper support pole into the lower one. Since the connection is not rigid, unintentional rotation usually occurs, especially when the insertion tube/cable is twisted. Specifically, there are spikes in both vertical movement and horizontal movement at a location slightly above 1.5 m from the roofline when scoping the dried borehole. The vertical movement is negative, and the horizontal movement is positive, indicating the borescope moved up and rotated right. This potentially resulted from the operations to disconnect the support poles. Normally, support poles get disconnected by gravity and fall to the ground automatically. However, it may get stuck with mud. The moving pole would hit the floor. It needs to be lifted and disconnected with small twisting. Another problem encountered during the recordings is that the connected support poles can get stuck when moving in the boreholes, potentially resulting from the shifting of roof strata or borehole deviation. The borescope needs to move up and down to get through, leading to the negative vertical movements.

In addition, Figure 8 shows that the averaged vertical movement when scoping the freshly drilled borehole is larger than that with the washed and dried borehole, which is further larger than when scoping the freshly washed borehole. This corresponds to the fact that it took the longest time to scope the freshly washed borehole. It took about 103 seconds to scope the 2.56-m deep borehole under freshly drilled condition, 243 seconds under freshly washed condition, and 143 seconds under washed and dried condition. Due to the water reflection in the freshly washed borehole, the borescope moved slowly when scoping the borehole, which took the longest time. With a longer time to scope a borehole, there are more video frames to analyze and stitch, and relatively smaller offset values can be expected between adjacent frames.

Furthermore, the borescope movement at the break points was investigated. As marked in the plots in Figure 8, there are 13 break points, and they were all from the video recorded with the freshly washed borehole, while the videos recorded with the freshly drilled borehole and the washed and dried borehole were successfully stitched. It can be found from the vertical movement in Figure 8 that, in general, there were faster-than-normal movements at the locations of break points when scoping the freshly washed borehole. However, there were much faster vertical movements or large rotations for the other two videos where the images were still successfully stitched together. These observations indicate that, besides the borescope movement, there are other factors affecting the image stitching process, and the borehole condition is one of these potential factors. As shown in Figure 7 (b), water remains on the freshly washed borehole wall and leads to reflection of camera light on the borehole image, affecting the key point detection and matching. This increases the difficulties in successfully stitching the borehole image. The reflection can further blur the borehole images with fast borescope movement. Thus, the combination of abnormal borehole movement and water reflection lead to the break points in the panoramic image of the freshly washed borehole.

The Influence on the Identification of Lithology and Geologic Features

The three videos recorded under different borehole conditions were processed to generate the panoramic borehole images, which are shown in Figure 9. It should be noted it is hard to ensure that the side-view borescope followed the same route and faced the same direction and minor difference may be observed in the panoramic borehole images under different conditions. A few observations can be made from Figure 9. Since there are multiple break points for the freshly washed borehole, the corresponding panoramic borehole image is longer than the other two borehole images. Also, due to the large height (borehole depth) to width (borehole diameter) ratio, it is difficult to demonstrate the panoramic images in detail, and instead, two marked locations were zoomed in to show the details.

The comparison of the three borehole images in Figure 9 indicates that the presence of dusts has significant and negative effects on the visualization and identification of geologic features and lithology changes, while the influence of water is significant and positive. The rock dust generated during drilling could cover the borehole walls, making it difficult to visually observe the geologic features and lithology changes. This is clear when comparing the enlarged view of three segments at the top marked location in Figure 9. Also, Figure 9 shows that the rock dust almost fills the fracture within the roof strata at the bottom marked location. This adds difficulties in geologic mapping. In contrast, the washing of the borehole removed the dust and

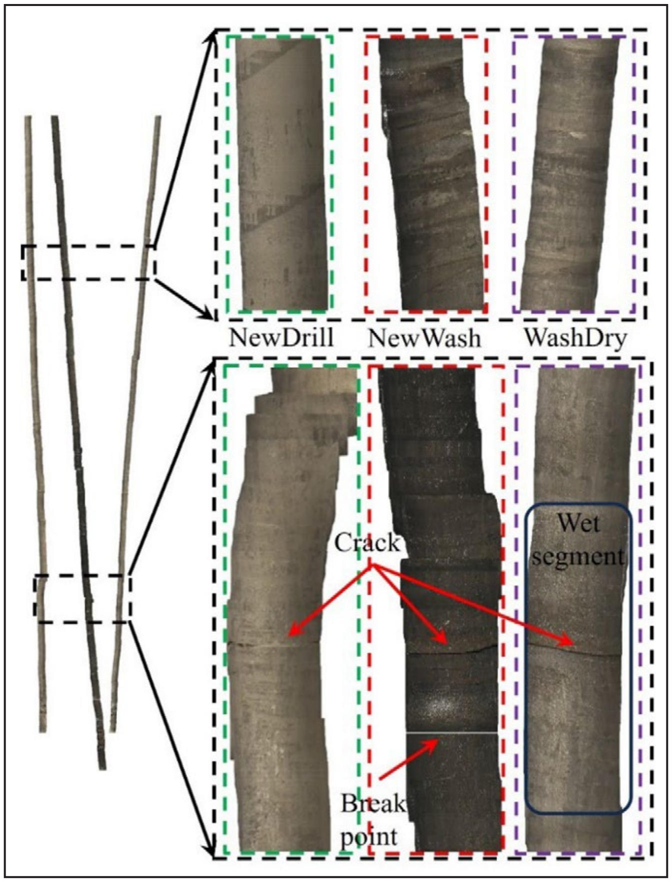

Figure 9. Generated panoramic borehole images under three different conditions with enlarged views for geologic features

increased the visibility of geologic features, including the fracture. Furthermore, water enhances the color contrast of rocks and helps to accentuate the differences between adjacent rock types, favorable for identifying lithology changes on borehole walls.

First, water can darken the surface of rocks. The freshly washed borehole has a darker color than the freshly drilled one and the washed and dried one. However, this effect varies with rock type. Different lithologies, like sandstone, shale, and coal, may react differently to water. Sandstone and shale will darken to different extents when wet and makes it easier to distinguish between layers with different compositions. If the rocks have different mineral contents, water will highlight these differences by deepening the color contrast. Organic-rich shale might become very dark or black when wet, and iron-rich layers may show more reddish or brownish tones. Wet coal seams will stand out due to the very dark, glossy appearance. Specifically for laminated shale, as shown in Figure 7 (b), water highlights subtle differences between fine layers by making lamination or thin bedding more pronounced.

In addition, water accentuates the differences in grain size and porosity of adjacent lithologies. Sandstone has coarser grains and absorbs water differently compared to fine-grained rocks, like shale or siltstone. Fine-grained shales will develop a smoother, more uniform darkening when wet. Coarser sandstones may appear rougher and absorb water more deeply, making transitions to finer-grained rocks more evident.

Finally, different rocks have varying porosities and permeabilities, affecting how they absorb water. Sandstones have higher porosity and will absorb water quickly, potentially remaining wet for a longer time than the rocks with lower porosity, like shale or siltstone. Shales and siltstones cannot absorb as much water and may dry out more quickly. As shown at the bottom marked location in Figure 9, there is one segment in the washed and dried borehole with the presence of water on the wall. The video was recorded 12 days after washing and all the other sections are dried. Although it is difficult to identify the lithology or lithology change from the borehole images, the presence of water after 12 days indicates that, at least, the porosity for this section is higher than that of the other dried sections.

In summary, water can significantly aid in identifying lithological changes in borehole surfaces by enhancing color contrasts, highlighting bedding planes and fractures, and accentuating differences in porosity and grain size. Wetting makes transitions between different rock types, such as between sandstone, shale, siltstone, and coal, more visible by enhancing textural and color contrasts, and revealing natural features like cleats, veins, and fractures.

CONCLUSIONS

In this study, the influence of borehole conditions on panoramic borehole images was studied by processing the borehole videos recorded under different conditions for the same borehole. The results show that the image stitching process can be affected by the borescope movement and borehole condition, and thus, the analysis of the influence of borehole condition was combined with the borescope movement. The borehole videos recorded in the freshly drilled borehole and the washed and dried borehole were successfully stitching as panoramic borehole images, while the stitching failed 13 times when processing the video recorded within the freshly washed borehole. The results show that the stitching failures all occurred with relatively large vertical and/or horizontal movements with water on the borehole wall. The combination of these two conditions can have significant adverse effects on the image stitching process.

For the visibility of geologic features and lithology changes, the dust in the freshly drilled borehole covers the true geologic features for geologic mapping and has significant adverse effects on the visualization and identification of geologic features and lithology changes. In comparison, water has significant and favorable influence on the visibility of geologic features and lithology changes by increasing the color contrast between different rock layers, accentuating the differences in grain size and porosity of adjacent lithologies, and removing the rock dust covering borehole walls. The boreholes after washing and drying can show the geologic features clearly, but it is difficult to identify lithology change because of the similar colors of coal measures rocks.

In summary, the presence of dust has a negligible influence on the image stitching process and has significantly adverse influence on the visibility of geologic features and lithology changes, while the image stitching process can be significantly affected by the presence of water on the borehole walls, which in turn helps in identifying lithology change. The preliminary findings from this study demonstrate that borehole conditions can affect the geologic mapping through panoramic borehole images, and further studies expanding the conditions may leads towards the identification of optimum borescoping conditions.

LIMITATIONS

The study was limited to the three videos recorded in the same borehole which mainly consists of shale and the conclusions are valid only for the conditions within the scope of the study. Further studies with different rock types with repeatability would have to occur before more evidence can be provided towards optimum conditions for geologic mapping through panoramic borehole images. Also, the conclusions were drawn based on the use of the IPLEX GX video borescope from Olympus America. The applicability of the conclusions to other borescopes needs to be further verified.

DISCLAIMER

The findings and conclusions in this study are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC). Mention of any company or product does not constitute endorsement by NIOSH.

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