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Chiaroscuro Photogrammetry: Revolutionizing 3D Modeling in Low Light Conditions for Archaeological Sites

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ABSTRACT
Archaeologists working in low light conditions have had difficulty producing 3D models that are both scientific and aesthetic. We are presenting chiaroscuro photogrammetry, a technique inspired by Renaissance artists, to solve this problem. The method is portable, inexpensive, low impact, adaptable, fast, and requires no additional expertise beyond photogrammetry. While first trialed on a rock and a tree that produced promising outcomes, the true test was on a panel of finger flutings in a completely dark chamber of Koonalda Cave, South Australia. The result was a 3D model of the finger flutings with evenly balanced light and deep colors, and the geometry of the model was free from holes and visible artifacts. The 3D model produced using chiaroscuro photogrammetry was visually and geometrically accurate, even more so than flash photogrammetry. Chiaroscuro photogrammetry has the potential to revolutionize 3D modeling in low light conditions for a variety of archaeological contexts.

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Introduction

Photogrammetry, the creation of 3D models from images, relies on images taken by cameras that have passive light sensors; therefore, unlike laser scanning, they require an external light source. Low or no light conditions have been a bane for many archaeologists working in dark caves because trying to collect images for photogrammetry in this environment requires an artificial light source. For well-funded projects, this means either mastering flash photography or transporting studio lights and power sources into the cave to capture images for photogrammetry. Another consideration is that the lights have to be low impact on the cave by not emitting excessive heat, and even then, custodians are often cautious about their use in caves for extended periods of time. In this paper, we propose a method that is portable, inexpensive, low impact, adaptable, fast, and requires no additional expertise beyond photogrammetry.

While many archaeologists look for solutions in the sciences, such as remote sensing (Bewley, Crutchley, and Shell 2005; Jalandoni 2021), machine learning (Jalandoni, Zhang, and Zaidi 2022), and geographic information system (Wheatley and Gillings 2002), we revisit a visual arts technique developed by Renaissance artists Leonardo da Vinci and Caravaggio: chiaroscuro. Chiaroscuro, which translates to "light-dark," is the use of strong contrasts of light and dark in visual compositions and is a technique still used today in photography, such as the photograph of Stonehenge used for the cover of National Geographic in 2022.

The impetus to trial chiaroscuro for photogrammetry was to produce a photogrammetric model of finger flutings located in a completely dark and deep chamber of Koonalda Cave in South Australia, the largest finger fluting site in the world (Figure 1A; Flood 1997). Finger flutings are impressions made by dragging one or more fingers across a soft, compactable surface such as calcium carbonate. Early research considered these marks to be parasite lines (Breuil 1952), and they were first thought to have resulted from animal or other non-anthropogenic activity (Nowell and Van Gelder 2020). By the 1960s, when finger flutings in Koonalda were being investigated, research elsewhere had shifted to confirming a human origin for these types of marks (Breuil and Berger-Kirchener 1961). The flutings in Koonalda were thus discussed in terms of their anthropogenic origin, with a particular focus on communication (Edwards and Maynard 1967; Gallus 1968, 1977; Maynard and Edwards 1971).

Photogrammetric modeling has not been done before in Koonalda Cave, apart from a preliminary trial in 2013 resulting in a single, unpublished image (Figure 1B). We wanted to find out if the data collected with chiaroscuro lighting, from here on referred to as "chiaroscuro photogrammetry," can produce a 3D model of finger flutings that is visually aesthetic and usable for scientific inquiry.

We structure the paper starting with a background of Koonalda Cave. Second, we elaborate on the role of imaging in sciences, chiaroscuro in art and photography, technical elements of low light photography, and chiaroscuro photogrammetry for rock art. Third, we detail the methodology, which included trials of chiaroscuro photogrammetry on a rock and a tree at dawn in Macintosh Park, Gold Coast, before attempting both chiaroscuro and flash photogrammetry on finger flutings in Koonalda Cave. Next, we share the results of the chiaroscuro photogrammetry trial on the rock and tree, and the flash and chiaroscuro photogrammetry of the finger flutings in Koonalda Cave. Finally, we discuss the implications of chiaroscuro photogrammetry for scientific research and the aesthetic appreciation of Koonalda Cave and the potential application at other types of archaeological sites with markings.

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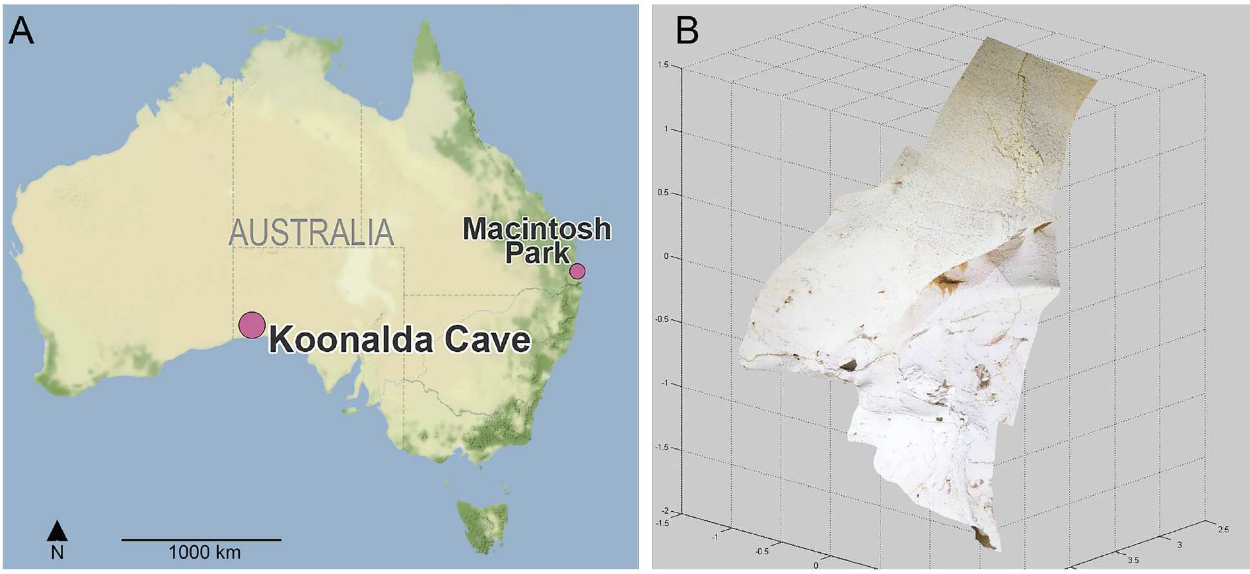

Figure 1. A) Map of Australia showing location of Macintosh Park and Koonalda Cave. B) Photogrammetry of finger flutings at Koonalda Cave (2013 image provided by George Poropat, formerly with Autonomous Systems, CSIRO, Brisbane).

Study Area: Koonalda Cave

Koonalda Cave is situated on the Nullarbor Plain of South Australia approximately 1200 km west of Adelaide. It is a place of high cultural and natural significance and was awarded National Heritage status in 2014, principally for its Indigenous heritage values. It also has a unique and intriguing archaeological history of disputed antiquity and terminology between two research teams simultaneously excavating in the cave (Walshe 2008; Wright 1971).

The cave consists of two main interlinked chambers or passages, one of which (northwest) contains engravings, while the north passage is characterized by lakes and ponds. These chambers are approximately 60–80 m below ground surface. Engravings are considered petroglyphs (McDonald and Clayton 2016), and here we refer to two distinct forms better known as finger flutings and incisions. The former have been made by pressing gently onto the walls of "montmilch" or "moonmilk" and the latter made by cutting into harder surfaces of wall or boulders with wood, bone, or stone. Moonmilk is precipitated carbonate, in this case calcium, resulting from decaying limestone, and it is limestone that constitutes the Nullarbor Plain. Koonalda Cave is a deep cave that has formed through mechanical adjustment and solution activity within the limestone karst (Frank 1971).

Indigenous people have for at least 22,000 years and probably more than 30,000 years ventured into the cave to extract flint and to engrave on walls and boulders (Walshe 2017). Boulders have accumulated in massive heaps due to periodic roof collapse. Both chambers were regularly visited by Indigenous people, but it is the northwest chamber where significant archaeological evidence has been uncovered (Gallus 1968; Wright 1971). This chamber is approximately 250 m in length but discontinuous due to a massive 20 m pile of rubble known as the "ramparts" (Zlot and Bosse 2014). The ramparts can be ascended on foot to access the deepest part of the chamber where the engravings, particularly finger flutings, are most evident.

The ramparts block out the diffused natural light that partially reaches into the main chamber through a north facing opening high above its floor. Previously, the issue of light for archaeological purposes has been resolved by carrying in candles, torches, and light stands, each of which have limitations in regard to weight and duration. Light from such devices is also uneven and difficult to control if set on a floor composed of roof collapse.

Boulders between the ramparts and the art chamber, in which the finger flutings dominate, exhibit incised engravings due to their consistently hard surface. These engravings are sporadic and restricted, unlike the approximately 350 m of wall surface in the art chamber covered in finger flutings (Maynard and Edwards 1971). Areas of wall without moonmilk are harder, and here engravings have been made by cutting in with a stick, bone, or stone. The finger flutings have increasingly preoccupied research interest since Koonalda was first explored archaeologically due to their excellent preservation in the art chamber and for their enigmatic nature (Edwards and Maynard 1967; Gallus 1968, 1977).

Photographing (SLR), measuring, and sketching demarcated surface sections of walls and boulders have underpinned the methodology for recording finger flutings and other engravings since the 1960s. The aim of these early studies was, first, to affirm their anthropogenic origins rather than being the result of animal activity or chemical erosion (Edwards and Maynard 1967; Gallus 1968; Maynard and Edwards 1971). Second, the research sought to interpret the markings by finding patterns or repetitive sequences (codes) that could be construed as mnemonic (Gallus 1968, 1977; Sharpe 1973a, 1973b; Sharpe, Lacombe, and Fawbert 2002; Sharpe and Sharpe 1976). This approach was highly influenced by Marshack's (1972) investigation of symbolic marks in caves and on artifacts and by Gallus's (1968, 1977) exploration of psychograms based on Jungian archetypes. In sum, the focus of earlier research on engravings in Koonalda Cave between ca. 1965 and 1985 was to affirm their cultural origin and to posit the marks as a proto language or form of proto art (Maynard and Edwards 1971; Sharpe 1973a, 1973b, 1977; Sharpe, Lacombe, and Fawbert 2002; Sharpe and Sharpe 1976). Overall, the engravings were considered as a proto language or proto art rather than as ritualistic and shamanic behavior, which were relevant within a European context (Gallus 1977; Maynard and Edwards 1971; Sharpe and Sharpe 1976).

A hiatus in Koonalda Cave fieldwork after ca. 1985 was due largely to lack of funding, and it was not until 2012–2013 that archaeological investigation recommenced with a trial of new technology produced under the auspices of the former Autonomous Systems Unit, CSIRO, Brisbane (Slezak 2012). This led to the first digital mapping of Koonalda with a multiple Zebedee system and a small-scale photogrammetry trial by Robert Zlot, Mike Bosse, and George Poropat (Zlot and Bosse 2014).

By this time, a core shift at the interpretative level was well underway. Research on finger flutings elsewhere, particularly in France, had shifted to focusing on the presence of children in caves rather than cogitating on codes and ritualistic behavior. At Koonalda, for practical reasons, the earlier method of recording finger flutings by using single lens photography and measuring fluting widths with a photographic scale continued, in order to find flutings potentially made by children (Van Gelder 2015).

The possibility of children making marks in caves both in Australia and Europe was first posed by Bednarik (1986), although C. Sharpe (1973a, 1973b) did question the level of maturity required to make marks in caves. Ensuing experimental techniques attempted to establish baselines for identifying engravings made by children to use as a mnemonic device (Sharpe, Lacombe, and Fawbert 1998, 2002). These were gradually refined, resulting in a dataset correlating age with fluting width measurements (Sharpe and Van Gelder 2006). Although the reliability of this data has been recently queried (Walshe, Nowell, and Floyd 2024), the presence of children in Koonalda Cave is considered highly probable given the presence of numerous children's hand prints in other Nullarbor caves (Cane and Gara 1989).

The advantage of applying digital technology, particularly photogrammetry to the recording of finger flutings (and other engraving styles) in Koonalda Cave is to increase rigor and accuracy in the measuring of flutings. With increasing global interest in the role of children in generating Palaeolithic art (Nowell 2021), accuracy and reliability in, firstly, identifying their presence is paramount. It is imagined that ultimately new digital based methods will shift beyond measuring and return the focus to a broader archaeological context. Such methods will also enable a return to all forms of engravings in sites such as Koonalda Cave rather than focusing explicitly on finger flutings.

Another and perhaps no less important application of photogrammetry rests in registering graffiti damage and other forms of deliberate or environmental destruction of engravings in caves. Extensive and irreparable damage was recently perpetrated in Koonalda Cave (Cominos, Ward, and Coe 2023). Recent fieldwork undertook digital recording of modern and historic graffiti at the site. This work has played a pivotal role in leveraging funding for more robust protective measures of this National Heritage site. Protection of Koonalda is of primary importance for Traditional Owners, cultural custodians, and native title holders for the broader region of the Far West Coast, South Australia. Native Title was determined over this region in 2014, and since then, joint management between the Native Title Representative Body for the Far West Coast Aboriginal Corporation and the Department of Environment, South Australia, has been established over existing Nullarbor national parks, reserves, and wilderness areas. Separately, the Native Title Representative Body for the Far West Coast Aboriginal Corporation (FWCAC NTRB) develops its own protocols for access of registered sites and cultural places. The FWCAC NTRB is certainly concerned about recent and historic graffiti damage inside Koonalda but has also expressed concern over the potential impact on cultural heritage from shifting climatic conditions for the Nullarbor region. Establishing a broad range of benchmarks for monitoring change to internal features and conditions needs to be more accurate and expedient. Generating digital 3D records of the finger fluting and the larger site results in a baseline record that can be used to detect far more quickly and accurately any change in internal conditions (Jalandoni and Tacon 2018).

Theory

The role of imaging in the sciences

"Today science needs its voice. It needs the vivification of the visual image, the warm human quality of imagination added to its austere and stern disciplines. It needs to speak to the people in terms they will understand. They can understand photography preeminently" (Abbott 1939, unpaginated letter).

Photography has played an important role in the sciences, from making information more accessible to a general audience through visualizing specific topics of interest to scientific innovations in photomicrography, astrophotography, and x-ray that surpass the limits of human vision: making the invisible visible and contributing to significant scientific discoveries. As early as A.D. 1887, Eadweard Muybridge's photographic high-speed experiments settled a longstanding dispute as to whether a running horse ever had all four feet in the air simultaneously (the answer was yes; The MET 2023). These imaging techniques have since been refined, achieving new heights. For example, the recent Webb Space Telescope delivers never before seen high resolution images of spectacular stars and spiraling galaxies, including 3D details of pillars inside dust clouds in which new stars are born (Witze 2022).

Deep space imaging teaches us that we can gain more scientific insights by exploring color, brightness, and contrast in photography (Witze 2022). The importance of contrast and lighting in scientific photography is evident in the way it can reveal details that are not visible to the naked eye. The use of contrast can help to highlight specific features of an object, while lighting can be used to create depth and texture, making the image more informative and visually appealing, even to a point where we start adding three-dimensional qualities to the image. Further, the creative use of lighting and contrast can help to make scientific images more engaging and accessible to a wider audience, allowing scientists to communicate their findings more effectively, just like the spectacular Webb Telescope images.

Chiaroscuro in art and photography

Chiaroscuro is the term used in visual arts to describe a tonal contrast of light and dark in the suggested volume and dimensional modeling of a subject in a drawing or painting (Figure 2). Artists like Leonardo da Vinci and Caravaggio are famous for using this technique to add to the three-dimensional quality of figures in their paintings (Bell 1995; Bleek 2016; Rzepińska and Malcharek 1986). This presents an interesting area for further exploration into the usefulness

Figure 2. *Lady with an Ermine (Portrait of Cecilia Gallerani)* is widely attributed to Leonardo da Vinci due in part to the style of chiaroscuro (Vezzosi 1997).

of chiaroscuro in scientific imaging applications, specifically with regards to three-dimensionality. Caravaggio further explored the use of contrast for emotional impact and drama in his work (Witting and Patrizi 2012). These are important elements for producing engaging scientific imagery for the general public that create awareness and outreach. Haubt and Jalandoni (2019) emphasize that data should be multi-purpose, and it is important to optimize data for several outcomes. The use of chiaroscuro for photogrammetry has the potential to improve the geometry of a 3D model as a scientific output. However, it also has the aesthetic potential for public engagement as a non-measurable impact.

The technique provided Renaissance artists with an excellent tool to create spatial illusions of objects on a two-dimensional canvas. Tufte (1990, 12–36) described the importance of such techniques for information visualization, in what he calls "escaping flat-land," the issue of information being displayed in two-dimensional formats in books or on computer screens. Chiaroscuro has the potential to assist with information visualization and aesthetics, offering innovative ways of exploring objects and opening new avenues of inquiry.

The concept of chiaroscuro has been used in art photography as a new way of resolving low light situations and for aesthetic effect. Darren Jew used the technique to photograph a plane in low light conditions underwater using a torch to "paint with light" (Joffe 2015). Reuben Wu used aerial drone lighting, a technique he calls "terrestrial chiaroscuro," to capture the Neolithic site Stonehenge (Figure 3; Martin and Mphofe 2022). This allowed him to bring out textures and contrast, adjusting the lighting angles spontaneously using the drone, which in turn gave him a great deal of flexibility in the field and avoided having to set up lights on location or wait for natural daylight. The technique allowed both artists to evenly distribute light across the subject of their interest in low-light conditions, resulting in stunning high contrast imagery with vibrant deep colors, highlights, and in-depth contrast.

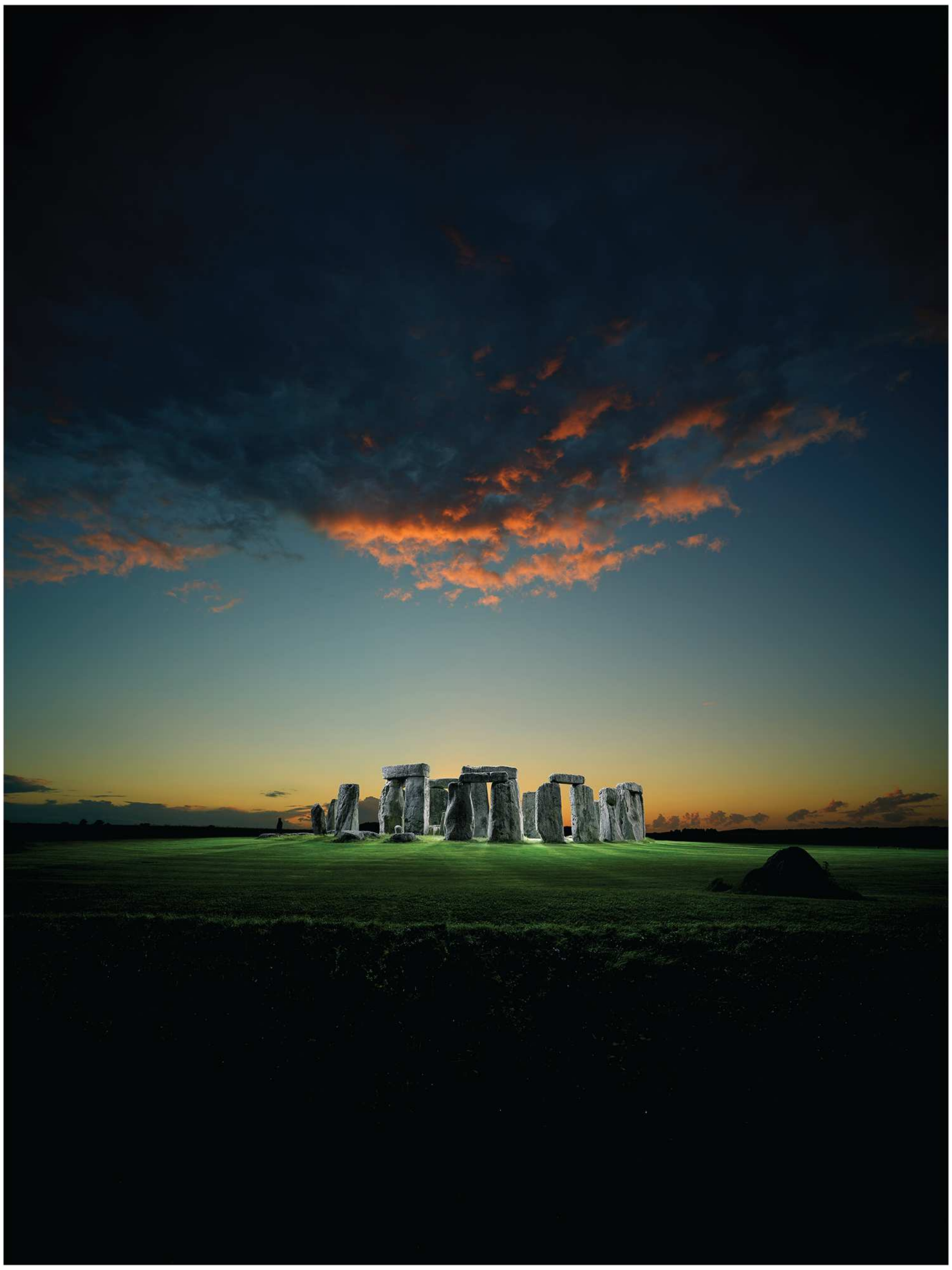

Figure 3. Chiaroscuro photography of Stonehenge by Reuben Wu.

Technical elements of low light photography

There are two elements in photography that determine the quality of light and contrast in the image: the light source and the camera settings.

Light source

The effect of the light source can be divided into three components (Hunter et al. 2021, 13–28). First, the size of the light source enhances directionality and intensity, which provides softer or sharper light on the subject. Second, reflections augment the direction of light, may provide more direct or diffused light, and contribute to light polarization. Third, reflective angles give direction of where the light sources originate.

As seen in Figure 4, a small light (1A) source, like a flashlight, produces more contrast and deeper colors, while a larger light (2A) source, like the sun on a cloudy day, produces a more evenly distributed light, which is softer but still maintains good contrast. We enhanced the vibrancy, saturation, and contrast in the image using the smaller light source (1B), which provides good contrast but obscures some of the three-dimensional quality in the image in highlighted (shadow vs. light) areas and can be less clear to read, as areas in the shadow seem to disappear. The larger light source (2B) provides a more balanced three-dimensional quality but washes out some of the color in the lighter areas. Chiaroscuro (3A) in photography, as used by Wu and Jew, has the potential to control the balance between larger and smaller light sources by using a small light source that moves over the subject like a larger light source; in other words, by producing omni-directional light when panned manually across the subject. "Painting with light" has the ability to tease out the color depth while maintaining balanced highlights, as we can see in the use of the larger light source. Image enhancements (3B) will therefore provide more contrast and color depth.

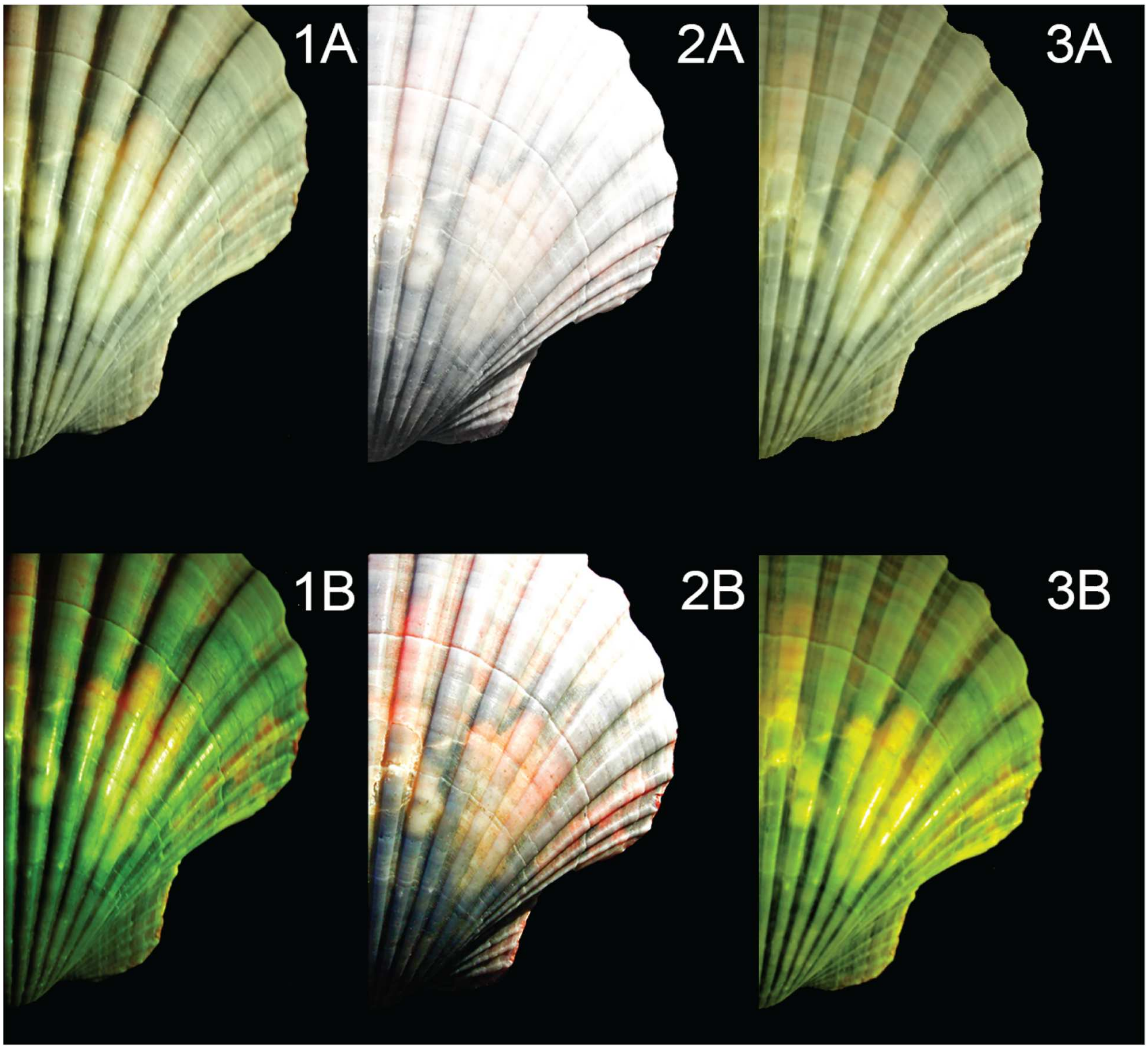

Figure 4. Image of the same shell using a 1A) small light source producing hard highlights and deep colors and 1B) image enhancement producing vibrant colors; 2A) the same shell using a big light source producing softer and more washed out colors and 2B) image enhancement producing more balanced colors. 3A) Chiaroscuro lighting showing great detail, contrast, and color depth in both original and 3B) image enhancement with balanced lights with deeper colors and contrast.

Camera settings

The digital camera settings that control light and contrast in an image are brightness, color, contrast, and ISO settings, the standard set by the International Organization for Standardization (ISO) that represents sensitivity to light of film and sensor chips as a numerical value (Hunter et al. 2021). Brightness is determined by the amount of light that falls onto the film or sensor of the camera and can be adjusted through the aperture, the opening and closing of the lens, and the shutter speed. In low light conditions, opening the lens and choosing a slower shutter speed will expose the sensor to more light. By contrast, closing the lens and increasing shutter speed can prevent images from being overexposed and too bright in very bright lighting conditions. However, shutter speed needs to be treated with care, as longer shutter speed time will also expose the sensor to light over longer periods of time and potentially blur the image if the camera or subjects are moving.

Considering color, high quality digital cameras such as Canon's EOS series introduced 12-bit depth and 14-bit depth around 2007. 12-bit depth provides around 4096 shades for red, green, and blue pixels, producing a theoretical maximum of 68 million colors, whereas 14-bit depth provides 16,384 shades, providing a theoretical maximum of 4 trillion colors. The maximum the human eye can detect is around 10–12 million colors, but higher color ranges allow one to later manipulate the image in high detail. Cameras can save files in RAW format for manipulation, but eventually photographers convert images back to JPEG with 8-bit depth, or around 256 shades that can produce around 16 million color tones.

Contrast is the difference between the light and dark areas in the image, and the dynamic range determines the span of dark and light areas that can be captured in the image. An external light-meter or a light-meter built into the camera can be used to measure the ratio of this range in f/stops. Each stop up or down will double or half the amount of light falling onto the image, respectively.

ISO in digital cameras simulates the sensitivity of the film and can be used to counter balance aperture and shutter speed settings to take brighter images in dark settings. Generally speaking, doubling the ISO speed, for example from 100 (low ISO) to 200, doubles the brightness of the image.

However, using higher ISO comes at a trade-off, introducing more grain (noise) to the image. Therefore, higher ISO settings should mainly be used if longer shutter speeds would blur a subject in the image due to camera movement or because an object is in motion.

Painting with light

From the above discussion, it is now clear how combining light source and camera settings can add contrast, depth, and dimensionality to an image. As seen in Figure 4, a small light source produces sharper contrast with more extreme highlights and blacked out areas (shadow and light), while a larger light source results in diffused light hitting the subject from multiple angles, making the subject appear softer with more balanced light.

For this project, we consider lighting subjects in dark conditions from different angles with a small light source. We "paint with light" by moving the light over the subject while keeping the exposure times extended. This evens out the distribution of the small light source while still providing more contrast from the small light. The result is a combination of large light for even balance and small light for richer colors and contrast.

Chiaroscuro photogrammetry for rock art

Chiaroscuro has not been explored widely in photogrammetry. One of the few examples is the use of night photography and photogrammetry to record an open-air site of engravings in Spain (López-Menchero et al. 2017). López-Menchero and colleagues (2017) provided some preliminary results on a similar method using night photography and concluded the quality was comparable to Reflectance Transformation Imaging (RTI) but easier to collect data. It is important to note that RTI is impractical for recording large sites, like Koonalda Cave, because it is limited by the range of the turning lights, as well as adding more bulky equipment (Jalandoni and Kottermair 2018; Mudge et al. 2006; Plisson and Zotkina 2015). The work described in this section further explores a photogrammetry flowchart and image pre-processing needs, as well as a deeper understanding of color depth, color distribution, and impact on shadow areas in the images used for processing.

Given the even distribution of the light on the subject as seen in Figure 4, it has the potential to tease out three-dimensional elements without obscuring the darker shadow areas, providing the computational photogrammetry model clearer texture data with each image, which should improve the photogrammetric model overall. Apart from the technical potential, it can also provide a way to improve Tufte's (1990) flat-land experience and add to the three-dimensional quality in information visualization towards better understanding of three-dimensionality in a two-dimensional image, adding to aesthetic appeal, communicating spatiality in new ways.

The impact of contrast in photographs for photogrammetry has been discussed at length by the photogrammetry community (Ballabeni et al. 2015; Bellavia, Fanfani, and Colombo 2015; Gaiani et al. 2016; Horé and Ziou 2010). Motayyeb and colleagues (2022) provide a flowchart that illustrates the role of luminance, contrast, and chromatic components in the image manipulation stages before the computational calibration, feature extraction, and development of the point cloud (Figure 5). Chiaroscuro has the potential to improve the quality of the image in all of these three stages. The luminance is improved by balanced light distribution without washing out the color and contrast, and the normalization and contrast is improved by even lighting, eliminating darker shadow areas while still providing high contrast on surface textures. The chromatic components are addressed by the color depth that a more evenly lit photograph using chiaroscuro exhibits (see Figure 4). Addressing these three stages should accelerate computational time, as well as improve feature extraction, improving recognition of clearer patterns, avoiding dark spills on shadow areas and providing more balanced color distribution.

Current practice in low-light rock art photogrammetry recording still utilizes standard lighting setup or no lighting using flash photography. Using small lights in flash photography can result in images with obscured darker shadow areas, while using larger light sources can produce washed out images (see Figure 4) (Cantó et al. 2022; El-Hakim, Fryer, and Picard 2004). Further, there is a limit as to how many lights can be installed and carried to the often-remote locations, limiting multi-lighting setup for hard to access places. Lighting conditions are essential for accurate and high quality photographic results considering the heterogeneity and irregular geometry or rock art (Cantó et al. 2022). While most photography literature mainly focuses on the latest technological advances, other aspects such as feasibility and practicality are often overlooked (Hunter et al. 2021, 299–300). As similarly identified by López-Menchero and colleagues (2017), chiaroscuro provides an easy, accessible, and lightweight option to improve lighting in low-light situations while further exhibiting excellent potential to improve the pre-processing stages of the computation photogrammetric process as seen in Figure 5. These capabilities (ease and weight) enable a rapid response to situations such as that recently reported for Koonalda Cave. The ability to quickly record destruction and reveal its extent is invaluable in formulating protective measures for sites.

Methods

General equipment and processing

A professional DSLR with fixed lens was used throughout the project: a Canon 6D Mark II with 35 mm lens. All datasets were processed on a computer with the specifications of 12th Gen Intel i9, 64GB DDR5 RAM, and NVIDIA GeForce RTX 3080Ti w/ 16GB GDDR6. All 3D models were processed with Agisoft Metashape Pro v2.0. PERAHU rock art scales were used for scaling the finger flutings models of Koonalda Cave (as used in Jalandoni and May 2020).

Images were captured in large JPG and RAW file formats, though only the JPG was used in the processing. It is best practice to capture in both formats, because JPG are smaller file sizes and therefore faster to process, especially in the field. However, should there be any issues with the JPG dataset, the RAW dataset, which is uncompressed and therefore captures more information, can be used to salvage the 3D model.

Processing parameters were standardized on all datasets. Alignment quality was High, no preselections, and key point and tie point set to infinity (0). To improve alignment, reconstruction uncertainty was set to 10, projection accuracy was set to 5, and cameras were optimized after each point deletion step. Batch processing was set up to generate dense point at High; Mesh surface type at arbitrary and

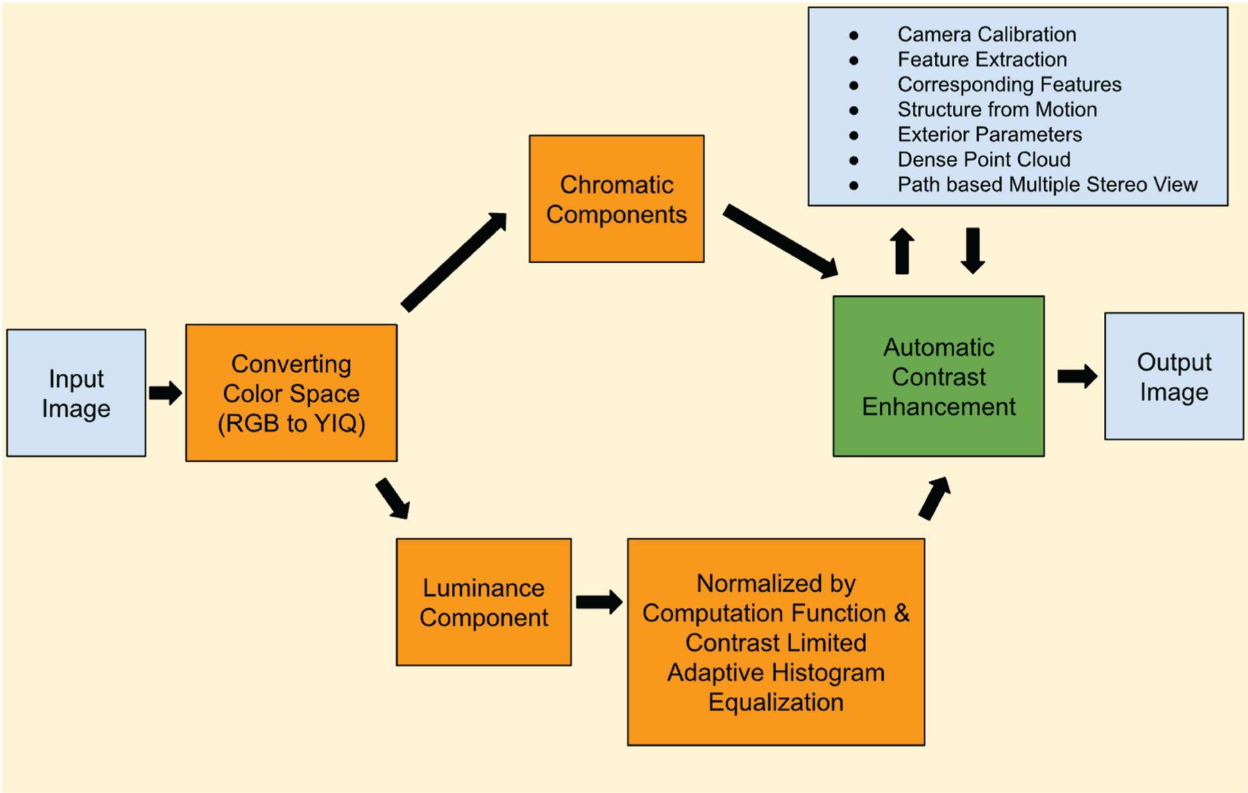

Figure 5. Photogrammetry flowchart for image pre-processing based on Motayyeb and colleagues (2022).

face count set to infinity (0); Texture mapping mode set to Generic, blending mode was Mosaic, and texture size was set to 8192; and, a Digital Elevation Model (DEM) was built from the point cloud. A compressed Agisoft Metashape project file (*.psz) with all the image data and fully processed models are available for download.

Testing on tree and rock at Macintosh Park, Gold Coast

Before trialing an untested method in a remote and culturally important site such as Koonalda, it was important to see whether photogrammetry was even possible with chiaroscuro. Therefore, tests were conducted on a tree and rock at Macintosh Park, Gold Coast at dawn. Using a tripod, nine images of a rock and eight images of a tree were captured in less than five minutes each (Figure 6A). Capture settings were ISO 100, F-stop 20, and shutter speed 10 seconds. The LED light beam was pointed at the object of interest, the rock for the first dataset and the tree for the second dataset, so that the autofocus correctly focused on the object. Alternatively, manual focus could have been used. When the shutter was activated, the LED light beam was waved over the object of interest in a pattern of left to right or top to bottom. The objective was to "paint with light" the whole object of interest that was visible in the capture area.

Flash and chiaroscuro at Koonalda

Flash

Data was captured handheld (no tripod), and the camera was set to F-stop 8. Three Canon 430EXlll Speedlite Flash lights with orange filters, bounce adaptors, and infrared triggers were brought. Two flashes were used, and one was backup. These particular flashes were priced at $300 USD each when new in 2015, totaling $900 USD. In 54 minutes, 76 images were captured. Processing the dataset took 80 minutes and 47 seconds (Table 1). However, additional time was needed for scaling the model, because the markers could not be automatically detected and had to be manually placed on the images.

Chiaroscuro

The camera was set to F-stop 14, and a tripod was used. A Manfrotto befree tripod costs approximately $200 USD; however, an argument can be made that tripods are already standard in the toolkits of many photogrammetrists. One Mini Cube LED light with a soft light diffuser was used, priced at $35 USD in 2022 and weighing less than 150 g with the dimensions of 50 × 45 × 45 mm. While not required during this study, the LED light can be recharged with a powerbank in the field and, if necessary, can be substituted with a headlamp. In 30 minutes, 63 images were captured. Processing the dataset took 67 minutes and 52 seconds (see Table 1). Markers were automatically detected, and the model was scaled after alignment.

Limitations

It would be misleading to present this as a definitive test of flash versus chiaroscuro because the data were not collected with the intention of being compared. Additionally, the results from someone who has mastered flash photography could be much better than those presented here. This experiment was conducted by a photogrammetrist who does not often use flash but had also never used chiaroscuro previously. This study demonstrated what can be accomplished with a novice ability in both lighting methods.

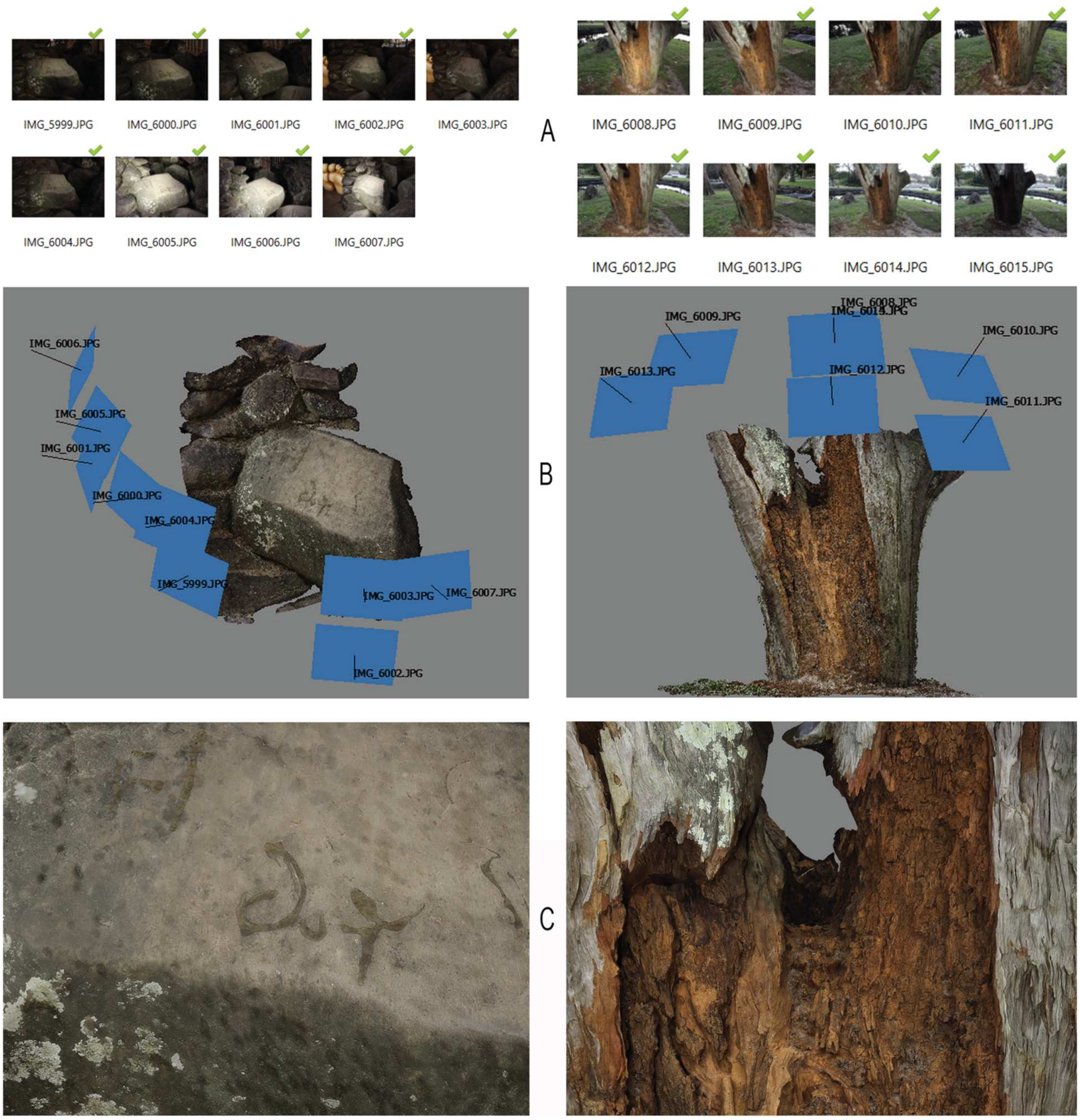

Figure 6. Chiaroscuro trial at Macintosh Park of a rock (left) and tree (right) showing A) images captured, B) camera positions and textured model, and C) close-up of model for detail.

Table 1. Flash and chiaroscuro processing time.

Method	Matching Alignment	Depth Map	Point Cloud	Mesh	Texture	Total
Flash	23′50″	15′04″	16′18″	5′06″	4′09″	64′27″
Chiaroscuro	12′27″	22′29″	11′15″	3′55″	3′23″	53′29″

It should be noted that Agisoft are constantly improving their algorithms in Metashape. It is uncertain if chiaroscuro lighted images will align as successfully in older versions. Up until at least 2021, the Agisoft Metashape Manual (Agisoft, LLC 2021) recommended avoiding flash for capturing images for photogrammetry.

Results

Macintosh Park: tree and rock

As seen in Figure 6, even with extremely varied light (see Figure 6A), the models had even color (Figure 6B) with accurate detail (Figure 6C). In addition to successfully 3D modeling the object of interest in low light, the method showed potential for shadowed areas. The tree in particular benefited from illuminating areas that would be shadowed even in natural light (see Figure 6C, right).

Koonalda Cave: finger flutings

The 3D model produced with chiaroscuro lighting is more evenly lit than the model produced using flash (Figure 7:1A, 2A), even if the individual photographs of the chiaroscuro dataset are not evenly lit (see Figure 6 for examples from the tree and rock or download files at http://hdl.handle.net/10072/424345 for Agisoft Metashape project). On closer inspection, the chiaroscuro photogrammetry model was more visually accurate than the flash photogrammetry model. The 3D model of the flash dataset had a hole, which is a lack of data, and blurred sections that had a smudged look (Figure 7:1B). While a hole in a model is a geometric problem and affects scientific research, it is also an aesthetic problem. The chiaroscuro dataset exhibits clarity and evenly balanced colors (Figure 7:2B).

Geometrically, both models produced DEMs. However, the DEM of the flash dataset (Figure 7:1C) contained more artifacts or defects in the model than the DEM of the chiaroscuro dataset (Figure 7:2C); therefore, the chiaroscuro model is more geometrically accurate. The importance of the DEM quality is that it can be used to enhance engravings for visualization and analysis (Jalandoni and Kottermair 2018) and for automated tracing of engravings (Jalandoni and Shuker 2021).

Even with the use of a tripod, the chiaroscuro dataset required almost half the capture time of the flash dataset (30 minutes versus 54). Faster data collection means less field time required, and therefore saves fieldwork costs. Aside from faster fieldwork, the flash dataset took 20% more time to process, though that is likely because 20% more images were used. However, even if fewer images were used for the chiaroscuro dataset, it produced a model that was free from holes and artifacts with evenly balanced light; therefore, it was more visually and geometrically accurate than the flash dataset.

Discussion

Benefits of chiaroscuro photogrammetry for finger flutings

Scientific research of Koonalda Cave

The approach to understanding finger flutings and other engravings in Koonalda Cave was originally influenced by seeking evidence of a proto language, proto art, and/or ritualistic/shamanic behavior to explain engravings. In line with a research shift in caves in southern France late last century, the approach to engravings in Koonalda Cave likewise moved towards focusing on individuals, particularly evidence for children in caves (Bednarik 1986; Sharpe and Van Gelder 2006; Van Gelder 2015). This methodological approach requires measuring the width of finger flutings, where three fingers (2D to 4D) have been held close together while they move as a stream (after Marshack 1977) across a soft substrate. Due to the fragile nature of flutings, measurements to estimate width can only be taken by holding calipers or a ruler away from the wall. In these studies, children's flutings are distinguished from those produced by adults by differences in width as little as 1 mm (Sharpe and Van Gelder 2006), and this method is subject to a degree of error—both in linear estimate and in observer error of up to 3 mm (Clooney 2013). Experimental trials by two subjects also indicated personal variation of up to 8 mm in creating three finger flutings (Sharpe and Van Gelder 2006, 195). In view of the 1 mm difference between a child's finger flute and that of a nonadult, a variation of 3 or 8 mm is problematic for precise identification. These limitations are not restricted to Koonalda but characterize finger flutings wherever they are found in the world (e.g., Rouffignac Cave, France), and therefore increased accuracy will enhance current global research into finger flutings.

Furthermore, using chiaroscuro photogrammetry, we can produce baseline 3D recordings of engravings in Koonalda Cave that the Mirning and Far West Coast Aboriginal Corporation can use to monitor for site deterioration by comparing this model both with future 3D recordings and past historic photographs. The urgency of this is highlighted by the recent (and historic) graffiti documented over engravings.

Aesthetic appreciation for public outreach

The 3D model is not only useful for scientific research, but it allows stakeholders and the wider community to engage with cultural heritage in new ways. The chiaroscuro photogrammetry captivated Mirning Traditional Owners and Far West Coast Aboriginal Corporation rangers by allowing them to see the digital 3D replica of a panel of finger flutings from Koonalda Cave. Engaging with cultural heritage improves well-being in general, but particularly among Indigenous people (Taçon and Baker 2019). While the digital version of engravings, or any rock art, cannot replace the experience of physically visiting the site, for some members of the community, it could be the only option (Jalandoni and May 2020). Koonalda Cave is the perfect example of a remote, hard to access site that not all Traditional Owners are able to visit in person to view important cultural features.

The 3D models can be converted to virtual interactive mediums that provide immersive ways of experiencing Koonalda Cave and the finger-flutings. These can be appreciated by Mirning and other cultural custodians. Dependent on the FWCAC NTRB, it may be of interest to the FWCAC and Nullarbor Advisory Group to offer wider engagement on a public level for approved aspects of cultural heritage. While digital records do not conserve the site, they preserve the visual information that can be appreciated by Indigenous people and the general public. They can also be used for cultural heritage management and further rock art research.

Other archaeological applications

The benefit of the chiarascuro photogrammetry extends beyond finger flutings to other low light contexts. López-Menchero and colleagues (2017) have demonstrated that the method can be used to record other types of engravings at night: therefore, in similar environmental conditions. The chiaroscuro photogrammetry should also work well for painted rock art sites in dark caves. For an art exhibit at the Guam Museum, photographer Victor Consaga used chiaroscuro to produce high-resolution photographs of the painted rock art of Guam, a US territory in the western Pacific, that are in low light and dark caves. Therefore, it is likely that chiaroscuro photogrammetry can produce a high-resolution 3D model of in situ painted rock art enclosed within dark areas.

The trial on the tree in Macintosh Park, Gold Coast, showed potential for improving 3D modeling of scarred trees. Scarred trees are trees where people have removed the bark for the purpose of making canoes, tools, shelter, clothing, and other artifacts. It can be difficult to do photogrammetry on the scarred area of a tree that is often in shadows. As demonstrated on the tree in Macintosh Park, chiaroscuro photogrammetry illuminated shadowed areas and could potentially illuminate the scarred area of the tree.

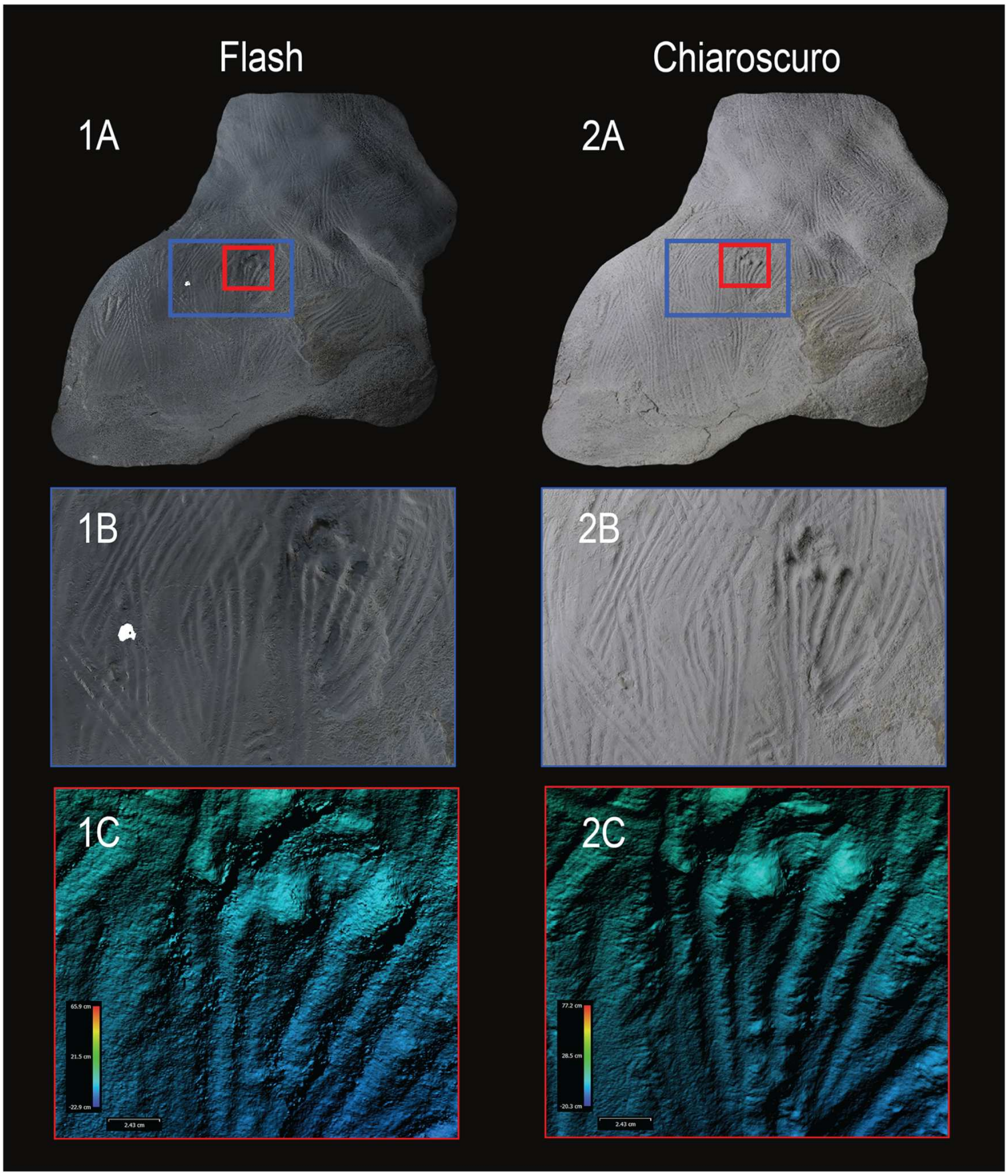

Figure 7. Image of textured model of the same Koonalda Cave finger fluting panel using 1A) flash and 2A) chiaroscuro photogrammetry. Close up of textured models showing 1B) a hole (lack of data) and blurred sections on the flash dataset and 2B) clarity of the chiaroscuro dataset. Digital elevation model of 1C) a section of flash dataset and 2C) chiaroscuro dataset showing difference in quality.

A number of significant historic prisons have been reimagined as places for public visitation (for example Piombi, Doge Palace Venice). These buildings carry centuries of marks made by former prisoners and a record of the marks becomes a significant archive in itself. Due to the architecture of prison systems, lighting is generally poor and in many ways similar to caves. The application of chiaroscuro photogrammetry to such contexts in order to digitally compile an archive of marks, script, and so on is invaluable. As discussed above, digital records also provide benchmarks for monitoring deliberate or inadvertent destruction when historic sites are made open to visitation.

Conclusion

Chiaroscuro photogrammetry delivered an effective solution for low and no light conditions that was portable, inexpensive, low impact, adaptable, fast, and required no expertise. The LED light was portable (< 150 g, 50 × 45 × 45 mm), inexpensive (ca. $25 USD), and is as low impact as a headlamp. In fact, a headlamp can be substituted for the LED light. Lighting an area with a handheld device is highly adaptable to a multitude of situations and allows flexibility in changing environments. It took less field time than flash photogrammetry, and a first time user was able to produce results that were scientifically usable and aesthetically pleasing for stakeholders.

While this method has tremendous implications for finger fluting research in Koonalda Cave, the application extends to photogrammetry in various archaeological contexts. It also provides important baseline recordings that are useful for monitoring the destruction and degradation of significant cultural heritage. Equally important is providing virtual access to the wide range of cultural custodians, native title holders, and/or other stakeholders who may struggle to meet the physical requirements for visiting sites deep below the ground or who are restricted geographically due to the long history of dislocation of people from their country. All of these challenges can be positively addressed by incorporating digital technologies as a platform for aesthetics, research, and access on an equitable basis.

There are undeniable advantages to adopting the latest technologies for archaeological research. Unfortunately, the majority of archaeologists do not have access to funding for expensive equipment or specialists to collaborate with them. We do not always have to look to the future for the methods to solve our problems. Inspiration can come from the arts, and given the long history of fascination with light, there is much on offer.

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