MOIRÉ CONTOURS FOR DOCUMENTING PETROGLYPHS AT MONTEZUMA CASTLE

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KEY WORDS: Moiré, historic documentation,

ABSTRACT

Great strides have been made in recent years in technologies for documenting our cultural heritage. These advances have usually occurred at large scales enabling, for example, the scanning of the Statue of Liberty or photogrammetric recording of very tall or unreachable objects. The tools developed for large-scale recording - Laser Scanners, Photogrammetry, and Total Stations are not suitable for heritage recording requirements below 3mm. I would like to speak about the development of an old technology for very fine depth requirements in heritage recording.

Moiré patterns are interference patterns that occur when a normative grid and a distorted grid are placed on top of one another. The distortion of the normative grid occurs when it is projected on non-planar surfaces. One kind of Moiré pattern contains contour (depth) information about that surface. This information can be combined with more traditional documentation tools to create 3D models of very subtly distorted surfaces.

In 2004 the Historic Resources Imaging Lab at Texas A&M finished detailed 2D documentation of Montezuma Castle at Camp Verde, Arizona. The walls at Montezuma are covered with various layers of mud "plastering" over stone. The plaster in its subtle textures contains much information about the Sinaguan construction techniques, their art- work, and later Anglo graffiti. Much of this information is impossible to capture adequately through photography and impossible to render in physical or digital models due to its subtlety: many markings and graffiti are fractions of a millimeter deep.

Moiré technology holds promise for capturing these markings for display physically or digitally, enabling a public that is barred from witnessing these Sinaguan practices directly to participate in them. This presentation will explain the initial stages of our research to enable these subtle Sinaguan practices to be brought down out of the castle and into public view.

1. INTRODUCTION

In 2002 the Historic Resources Imaging Lab was contracted by the National Park Service to create documents for Montezuma Castle in Camp Verde Arizona (Figure 1). The task was to complete HABS (Historic American Building Survey) Level 1 documentation, i.e., create plans sections and elevations. In the process of creating those documents – largely because of the irregularity and fragility of the building,-we were forced to pay close attention to the walls (Figure 2).

Figure 1. Montezuma Castle

Montezuma has been closed to the public since 1951 and no documentation has ever been completed save for a brief archaeological survey in 1988. The walls were of great importance, we were told, because they contained examples of "plastering" techniques (Figure 3, 4) by their Sinaguan builders dating to 1150 CE. One of the most remarkable things about the walls was the lack of wall paintings and markings. (pictographs and petroglyphs). This was inconsistent with other Sinaguan sites in the area though the inconsistency could be explained away by the difference in local materials and thus construction technique.

Figure 2. Level 3 Plan

The 1988 archeology report listed three major markings each in a different room. This paper is concerned with markings represented by two of those three (Figures 5, 6). Even with the excellent notes from the report these markings were difficult to find. The one in Figure 5 took a couple of weeks to find, while in the first season of documentation the one in Figure 6 was never found. However, in the second season a more careful search for Figure 6 was made and it was finally located exactly where the archaeologists noted.

Two things were remarkable to at that point, the first being the incredible detailed vision of the archaeologists who spent only a week in the building and the second being the fact that the subtlety of the noted markings didn't point to other markings with greater subtlety.

Figure 3. Hand Mudding

Figure 4. Smooth Mudding, Rm 3-3 Room 3-5

I was moved to make a search for other markings and discovered that, in fact, the Sinaguans at Montezuma Castle were not that much "quieter" with their art than their neighbors.

Figure 5. Scratch Markings on South Wall Rm.

Figure 6. Wet Mud Markings on 3-5 North Wall Rm 3-3

On the other hand, maybe they were "quieter" with their art but still as prolific. The problem at Montezuma, and I assume other places, is that the markings are so subtle they are virtually invisible. One significant contributor to their invisibility is the low light level in almost every room. It is not impossible but not easy to find your way without a flashlight. We didn't measure light levels but reading in these rooms is impossible without extra light. When we photographed the rooms during our initial season of documentation we used simple flash photography with the flash perpendicular to the walls. None of the markings were ever visible in these photographs. During our second season we therefore faced the problems of first, how to photograph the markings to show that they exist, and secondly how best to measure them.

Raking light was of course the obvious answer but how to do it was the problem. We tried flashlights – good but not consistent enough, lanterns – better than flashlights but very difficult to hold in position, and a combination of lantern/ flashlight and long exposure times to get what we could. The photographs were good enough to convince the park personnel that we had discovered some new markings but the markings still were almost ghostly in their ability to disappear when you concentrated on seeing them (Figure 7, 8).

Figure 7. Scratch Markings Rm. 3-5 Below Figure 5

Figure 8. Markings on South Wall Rm 3-7

After the fieldwork was complete and we were safely engaged in completing the drawings Dr. Al-Ratrout, a student of mine, began an earnest investigation on moiré. It was during this investigation that the thought of combining moiré with the documentation of the markings occurred

2. MOIRÉ CONTOURS

Traditional contour recording technologies, associated with point-to-point measurement principals tend to represent an object's surface based on point-to-point information. Some of the principals used are optical triangulation, stereoscopy and photogrammetry. Moiré techniques are unique in this scope as it incorporates the principle of integral measurement (Wegdam, 1991).

As an optical phenomenon, moiré was mentioned in the scientific literature more than a century ago. It was in Lord Rayleigh writings in 1874 when it was initially referred to as "bar patterns" (Sciammarella, 1960).

Since 1970, moiré techniques were involved heavily in producing measurements for topographic mapping of the human body without the need for physical contact (Kafri and Glatt, 1990). That involvement revealed that these techniques require simple equipment while providing geometric information with high accuracies (Karara, 1989).

Research in many fields confirmed that moiré as a recording technique is characterized by unique qualities. These recognized qualities are high sensitivity to in-plane instrument displacements, insensitivity to out-of-plane instrument displacements, compatibility with both large and small displacements with different object sizes, high contrast and visibility of the fringes, the ability to work remotely and in real time (Post *et al.*, 2000) and the techniques physical problems ability to be solved without involving mathematical calculations (Patorski, 1993).

As an optical phenomenon, moiré can be visualized by superimposing two closely identical grating of dark lines. By viewing these gratings against light background, dark fields called "moiré fringes" are observed. The dark fringes are caused by blocking light when the opaque areas in one pattern overlap the transparent or the opaque areas of the other. On the other hand, light areas between fringes results from overlapping the transparent areas of the two gratings (Amidror, 2000), as shown in Figure 9. The small differences in the spaces and the orientations between lines will affect the form and the spacing of the resulted dark fringes (Bryngdahi, 1992).

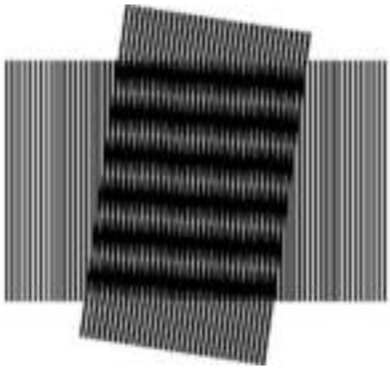

Figure 9. Moiré dark fringes from relative rotation of two grids.

As a recognition method for relief deformation, the base for moiré technique is the comparison of two states of identical line-gratings. The first state is the initial state (reference or unloaded line-grating), and the second state is the modified state (loaded line-gating associated with relief deformation of the object). The changes in the grating appearance from one state to the other reflect the perpendicular displacements experienced by the relief with respect to a reference plane.
In these visual combinations, the resulted dark fringes hold a record of the grating lines overlapping and separation locations. These locations reflect the relative changes that the original line pattern went though to reach the deformed pattern form. From these relative places, information about the in-plane deformation of the relief can be quantified in relation to a reference plane.
In general, moiré topography refers to the three main techniques (shadow, projection, and deformed grating types) commonly applied for the measuring and displaying of the object's three-dimensional form (Takasaki, 1981).
Shadow moiré technique can be produced using a light source and a reference grid placed close to the investigated surface, as shown in Figure 10(a). A shadow of the grid is cast on the object's surface. As a result of the object's surface deformation, the shadow of the grid is distorted from its original form. By arranging the light source and the viewing point at a known distance from the grid, moiré fringes are generated as topographic contours when the distorted shadow is observed through the reference grid, as shown in Figure 10(b) (Perkelsky and Wijk, 1989).

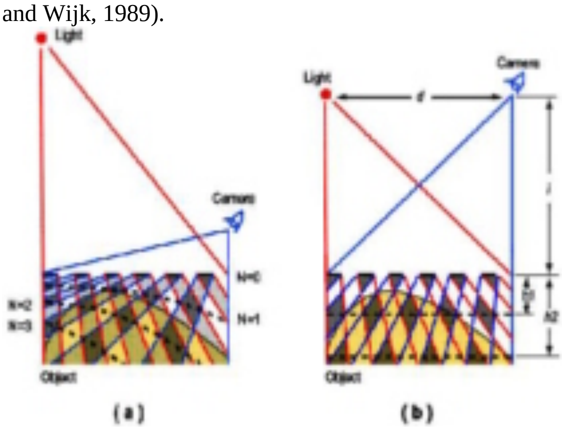

Figure 10. Shadow Moiré technique (Liu, 1985)

Generally, the sensitivity of all moiré techniques depends on the pitch of the grating used in the process. The sensitivity increases when the pitch projected on the specimen is reduced (Asundi, 2000). The geometry of moiré techniques is closely related to stereophotogrammetry. They are related in the sense that both techniques depend on two sets of imaging information produced from two related positions (Liu, 1985).
In stereo-photogrammetry, the two included images serve as a real representation of the object's visual characteristics. These two images are employed in extracting the spatial 3D location of any defined point that can be identified visually on the images of the object's surface (Perkelsky and Wijk, 1989).
In shadow moiré method, the technique assumes that the distorted shadow of the grating, when viewed from the light projector location, will look exactly like the same original grating with no distortion (according to that viewpoint). The other image from the camera location will record the reference grating overlapping the grating distorted shadow cast on the object surface. Based on that assumption, in order to encode the three-dimensional information related to the object's surface, only one set of imagery information is needed in shadow moiré technique.
As a relief deformation recognition method, the changes in the grid appearance from one state into the other hold the perpendicular displacements experienced by the surfaces with respect to a reference plane (Perkelsky and Wijk, 1989).
According to this, the encoded in-plane depth distance between the resulting moiré fringes depends on the distance to the object from the two projection centers (the camera and the light) as well as their relative distance from each other. Those three distances determine the resolution and accuracy of the depth information derived from moiré images, as they do in stereo-photogrammetry (Perkelsky and Wijk, 1989).
In that scope, moiré techniques are superior as they offer integral relief information that readily displays fringes reflecting the observed surface deformation (Wegdam, 1991). This important feature sets moiré apart from stereophotogrammetry where point-to-point measurements need to be defined and calculated to determine the surface deformation.

3. MOIRÉ RECORDING TESTS

Moiré is a promising method for quickly and accurately acquiring depth information for small scale and very irregular objects. In controlled situations one can control the variables of angle and distance sufficiently to gain metric accuracy far greater than our current state-of-the-art methods. This is especially important in cases like Montezuma Castle where interpretation is so vital since the public is prevented from enjoying a first-hand experience. Yet, as important as the metric capabilities are of moiré the basic intrigue for us was whether it held any promise as a visualization tool.
Its promise in this way can be seen very easily by taking an acetate sheet with lines printed on it and laying it on top of a bumpy object, e.g., a wadded up piece of paper. If done outside in the sunlight then the contours become immediately visible. Inside you can provide the light you need with a flashlight placed at any angle other than perpendicular to the sheet. Figure 11 shows a piece of paper on the ground. Figure 12 is that same piece of paper photographed through a moiré grating resulting in a shadow moiré effect and showing contours. The closer the spacing of the lines the greater is the resolution of the contours.
To qualitatively test these ideas for use in Montezuma Castle we constructed three marking types found in the building: 1. hand mudding (Figure 13), 2. wet mud figures (Figure 14), and
3. scratches in smooth surface (Figure 15). These figures were constructed in plaster on Styrofoam.

Figure 11. Paper on ground

Figure 12. Paper with Moiré grating

Figures 13 and 14 represent general mudding techniques and wet-mudding figures similar in nature to those founding room 3-3. Figure 15 represents the smooth surface in which markings were scratched. The best example is found in room 3-5 but as we discovered they occur on every level. We tried to be true to the lighting conditions found in Montezuma so we took photographs with flash perpendicular and under raking light. We then looked at photographs straight from the camera and those altered for brightness and contrast. We compared these with photographs taken under different grating levels, 25 lines per inch, 50 lines per inch, and 100 lines per inch.

Figure 15 presented the greatest practical challenge to the notion of a moiré visualization tool because the markings were so subtle. The model contains 3 different markings: 1. precise scratches made with a knife, 2. scrapes where the marks are wide and shallow, and 3. very shallow scratches. For purposes of visualization there seems to be some value in using moiré gratings to depict the wide scrapes.

Figure 15 shows the block as shot with a flash straight on. It is nearly impossible to see the shallow and wide scrapes while the deep scratches are visible. With the use of a moiré grating in Figure 16, the shallow scrape (2) and the deep scratch (1) become much more prominent though the shallow scratch (3) is still impossible to locate.

Figure 13. Hand Mudding Model

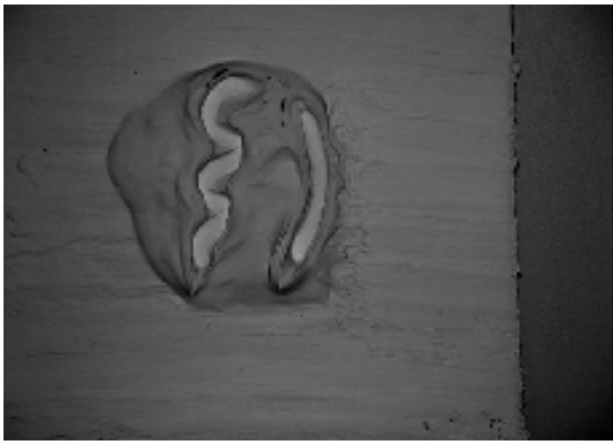

Figure 14. Wet Mud Figure Model

Figure 15. Smooth Mud Scratches

This test is not quite fair, however, since to perform moiré the supplied light and the camera must be a different angles. Thus, the light provided in the moiré example in figure 16 was a raking light. Figure 17 shows the same conditions under a raking light with no moiré screen. The image was taken at very high resolution 14mp from 4 ft. and enhanced for contrast and brightness on the computer. The shallow scratch is more visible in this case.

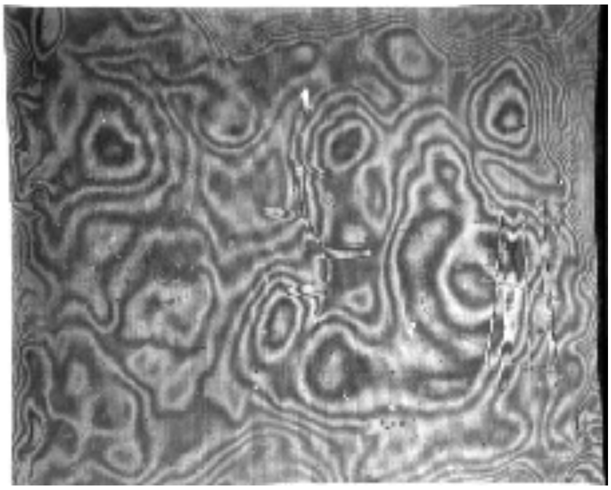

Figure 16

Figure 17

What is the value of a moiré screen if high resolution imaging will show you more? First, the visualizations occurring with the moiré screen are apparent to the naked eye allowing discovery "in the field" and possibly limiting the need to carefully photograph and process every inch of every wall. Secondly, with a bit more careful set-up the moiré screen allows for metric reproduction in 3D rather than simply tracing from a photograph.

The advantages of moiré are not in full affect under the conditions we employed. Since the screen spacing directly relates to the depth measurement a very tight grid spacing should yield the ability to create contours on very subtle surfaces. We did not have any of our gratings manufactured but instead relied upon the resolutions of our printers. We found that even on 1200 dpi printers the best we could reliably create was a line spacing of .01 inches thus giving us lines of .005 inch thickness. Beyond that range we encountered secondary moiré effects in the printing and such subtleness in lines that their shadows were very difficult to see.

For the more visible markings the moiré screen offers an excellent opportunity for 3D measurement. If a controlled setup is possible then the contours can be calculated and mapped from a single photograph. This information concerns, however only the depth. Standard techniques of rectified photography, total station, laser scanning, or photogrammetry can be used to gather the length and width information. Figures 18 and 19 demonstrate the use of shadow moiré on examples presented in Figures 14 and 15. Each figure is shown at 50 lines per in.

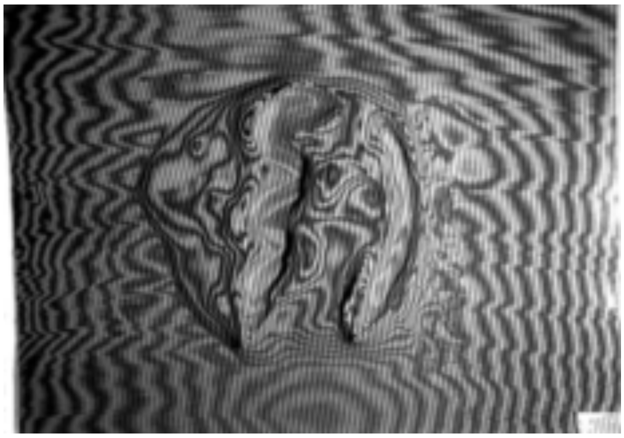

Figure 18. Wet Mud Figure Model with Moiré Screen

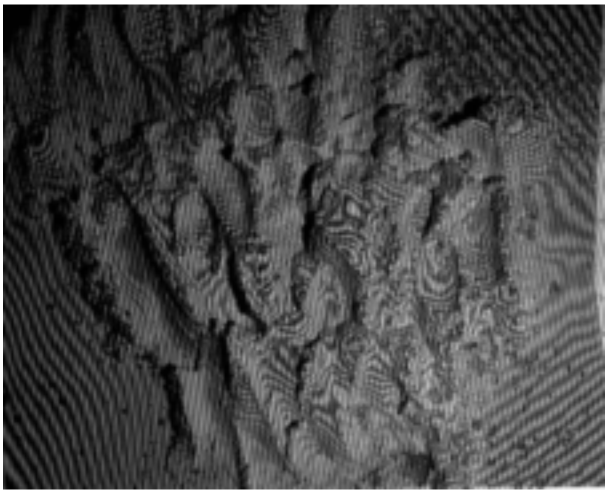

Figure 19. Hand Mud Model with Moiré Screen

4. CONCLUSION

These preliminary tests signify promise for utilizing moiré techniques as a metric and visualization tool. However there are still many field problems to overcome. These problems may yet be solved through technological developments in concert with practical ingenuity. We employed shadow moiré in these tests in an effort to increase the visibility of the moiré effect at higher resolutions. Creating large screens with high resolution and little deformation is a difficult task. One can circumvent these issues by utilizing projection moiré in overlapping two gratings created in Photoshop and projected by video projectors. Success is not limited in this case by the resolution of the grating but by the resolution of the projectors and the ability to control the amount of projected light. Video projectors tend to throw so much light that the moiré contours are washed out. With careful attention to detail moiré techniques offer the possibility of creating 3D models of very fine detail with relatively low investments time in-the-field and in production.

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