THE VIEW FROM ABOVE
OVERVIEW AND COMPARISON OF LOW COST AERIAL PHOTOGRAPHIC TECHNIQUES

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Abstract:
The view from above a structure, archaeological site or artwork gives conservators a unique perspective and powerful tool with which to make informed decisions. Such images can be used to create site plans, to identify boundaries, to assist in monitoring and analysis and for planning interventions. This is not new; architects, landscape architects, archaeologists, engineers, and city planners have been using aerial images from various sources for many years[1]. However, obtaining such images today from airplanes or helicopters can be expensive, prohibited in many locations, and are often beyond the budgets for many small projects. In addition, satellite images are often not of sufficient resolution for smaller sites, can be costly or out of date, and are usually only available vertically. Fortunately, there are alternative methods, technologies and strategies for inexpensively obtaining the 'view from above'[2],[3].
Many of these alternative methods are not new and some are as old as photography itself[4]. But recent advances in low-cost, high resolution digital cameras, higher capacity memory chips, low cost radio control systems and onboard camera and post processing software have made these techniques more accessible, affordable and efficient. These techniques are currently being investigated and most have been tested, used and taught on a variety of sites including land art, archaeological sites, mosaics, vertical murals, and complex roof structures. Simplicity, reliability and cost were key factors in the team's investigation and testing. It was also important for the team to investigate across techniques to compare and contrast to understand the advantages and disadvantages. The scope of this paper is to give an overview, presentation and comparison, with case studies, of these techniques and platforms – poles, balloons, kites, multicopters and fixed and flexible wing remote controlled aircraft.

1. OVERVIEW OF TOOLS AND TECHNIQUES FOR AERIAL PHOTOGRAPHY

The goal of this paper is to present an overview of the tools and techniques for aerial photography and describe the initial phase of this investigation. Continuous advances in consumer level, high quality, low cost digital cameras; on-camera programming and image processing and photogrammetric software have made these techniques more available and powerful. This has necessitated a review of these techniques. The authors have chosen to investigate low cost, easy-to-use tools for two reasons: 1) most small conservation and archaeological projects have limited budgets and 2) the procedures and tools for larger, more expensive projects are already well established. The authors also investigated at many different sites with a variety of tools and techniques for comparison to fully understand the advantages and disadvantages.

1.1 Pole photography

Images obtained from above do not have to be complicated or complex and can be as simple as mounting a camera on a pole. This technique is particularly useful for imaging floor mosaics or other smaller horizontal surfaces. Poles have been used for photographing from above before, however, with the recent advances in digital cameras combined with the ability to control every aspect of the image capture and 'stream' the resulting images down to a laptop computer have made this technique much more useful and user–friendly. This includes the software to combine the resultant images and remove radial and perspective distortion.

In March 2010, at the International Centre for the Study of the Preservation and Restoration of Cultural Property's (ICCROM) Built Heritage Course, this technique was used to photograph the mosaics in Chiesa di San Benedetto in Piscinula in Rome[5]. This church dates back to before the 15th century with portions dating earlier. Some accounts state that Saint Benedict studied here before becoming a hermit. It is located in Piazza Piscinula, Trastevere, and is said to have the smallest bell tower in Rome with beautiful mosaic floors covering portions of the nave.

A standard three-directional tripod head was mounted onto a telescopic aluminum window cleaning pole and hoisted at a 45 degree angle four meters over the mosaic. Two directions of the tripod head were fixed while the third direction was loosely tightened to ensure that the weight of the camera would point the lens 90 degrees vertical over the mosaic. The pole end opposite the camera was positioned on the floor at predetermined points to guarantee 40 degree overlapping coverage between images and held in place by one team member. The tripod head was raised and then stabilized with two cables by two additional team members. A fourth team member guided the process, measured the height of the camera using a Leica Disto EDM (electronic distance meter) and controlled the camera via laptop. A Nikon D60 with a 50mm prime lens was controlled from the laptop via a USB cable using the Breeze Systems and NK Remote software. This software allowed the camera to be completely controlled by the operator from the laptop including image preview, aperture, shutter speed and shutter release. Target tesserae (small stones that make up the mosaic) were then measured on the surface by triangulation using a Disto and a bubble level from three station points outside the subject area. The images were then corrected for radial distortion using PTGui and then combined in Photoshop and AutoCAD. While the software and measurements techniques could have been more sophisticated the primary objective of the ICCROM course was training, therefore the tools had to be readily available, easily understood and images captured and processed within three days. This technique was also used successfully to photograph horizontally from a higher vantage point for many of the chapel's frescos and for many of the following case studies. The results obtained from the pole photography provided the participants with distortion free images that were not otherwise available.

The chief advantages to this technique are that it is very inexpensive and can be used with no training. It also works well in cases of strong wind when other aerial techniques are severely restricted. The limitations, of course, are obvious; height is restricted to about eight meters for a three person team and to about three meters for someone working alone.

1.2 Balloon photography

The 'view from above' can be particularly compelling in the case of large-scale land art or archaeological sites. In 2009 helium balloon photography was investigated at Michael Heizer's *Double Negative*, Figure 1. *Double Negative* is a monumental sculpture sited on a sixty-acre parcel in the Nevada desert at the edge of the Mormon Mesa, located approximately 80 miles from Las Vegas, Nevada. A "sculpture in reverse," it was created in 1969 and addresses the absence of form[6].

Tests were conducted at different altitudes with various overlapping images utilizing targets and natural features as reference points to combine the final mosaic vertical image. Oblique images were also captured. The tests also included different cameras and lens configurations and post processing software. A Nikon D90 and Canon G9 were the primary cameras used for image capture. Control and transfer of the images were tested using wireless USB. However, the maximum range for wireless USB is approximately 20 meters and the images needed to be captured from a height of 50 meters. The signal range was extended to beyond 50 meters by placing the antenna in a parabolic wok pan, Figure 2. This functioned extremely well but the best control for the camera proved to be a software internal intervalometer. An intervalometer is a device that triggers the camera shutter at predetermined intervals. This entailed installing an alternative operating and script from the free, downloadable Canon Hack Development Kit (CDHK) software into the camera[7]. The camera was then re-programmed to begin taking images every six seconds. This allowed the camera to continue to take images for over two hours on 32 GB card while the balloon was aloft. Shutter speed and aperture were preset via the manual controls before launching the balloon and images were captured in the Canon Raw format. An 800 gram latex weather balloon was inflated with helium and tethered and controlled by three lines of 80 pound braided Dacron. Three lines provided greater control but two lines were determined to be sufficient. The lines and balloon were connected with aluminum carabineer clip and zip ties that held in place with a plastic disk which in turn held the camera. Other multiple balloon combinations were tested including two to five smaller balloons but one balloon proved to be the simplest and easiest to control.

The resulting images obtained during the project, clearly show the failure of the soft sandstone walls and resulting rubble at the bottom of *Double Negative*. The aerial images also give an overview of the piece that is not available from ground level.

Figure 1: Michael Heizer's Double Negative. Oblique image captured from balloon photography in the Nevada desert. *Eppich, Tang, Hinchman.*

Figure 2: Parabolic wok antenna extended the range of wireless USB from 20 m to over 50 m.

1.3 Balloon Photogrammetry

The next phase was to utilize balloon photography to create stereo pairs for photogrammetric processing and analysis. In the spring of 2011 this technique was utilized at the Islamic castle site at Onda in Eastern Spain near Valencia. Onda Castle, situated on an imposing hilltop above the city, was built by Muslims in the 11th century and includes a palatine residence. It was strategically located on entry routes between the Mediterranean and the Mountains of Sierra de Espadán. The small palace is located on the top of the site and externally has the aspect of a towered castle, while inside the halls and portico surround a square courtyard with a garden and pool[8]. To assist with the documentation of the excavation a set of aerial photographs was taken including stereo-pairs that allow for a complete 3D plotting of the structures of the palace. The pictures were oriented using the software Poivilliers F, developed by Yves Egels, with control points measured with a total station. The accuracy reached was greater than 2 cm. The pictures, at 12 mega pixels, were taken at an altitude of 45 m above the palace.

In addition to the capture of stereo pairs one of the improvements was a small inexpensive BlackWidow wireless camera, transmitter and receiver streaming video at 2.4GHz (with a range of up to 2 kilometers) to a laptop below. This secondary camera was used for targeting to ensure that the camera and balloon were positioned directly over the intended subject. In addition, the camera was 'spotted' using a Laser Technology TruPulse 360B laser ranger finder in order to target the balloon through the telescope to determine altitude. Adjustments were then made to the balloon height to achieve desired altitude. A team of three conducted the operations, one observing from the laptop and directing operations via cel telephones to ensure a complete stereo pair and the other two controlling the lines attached to the camera cradle. A 1200 gram latex weather balloon was used and filled to only 75% capacity, Figure 4. This ensured that there was ample flexibility in the latex membrane as well as sufficient lift to easily control the camera and cradle.

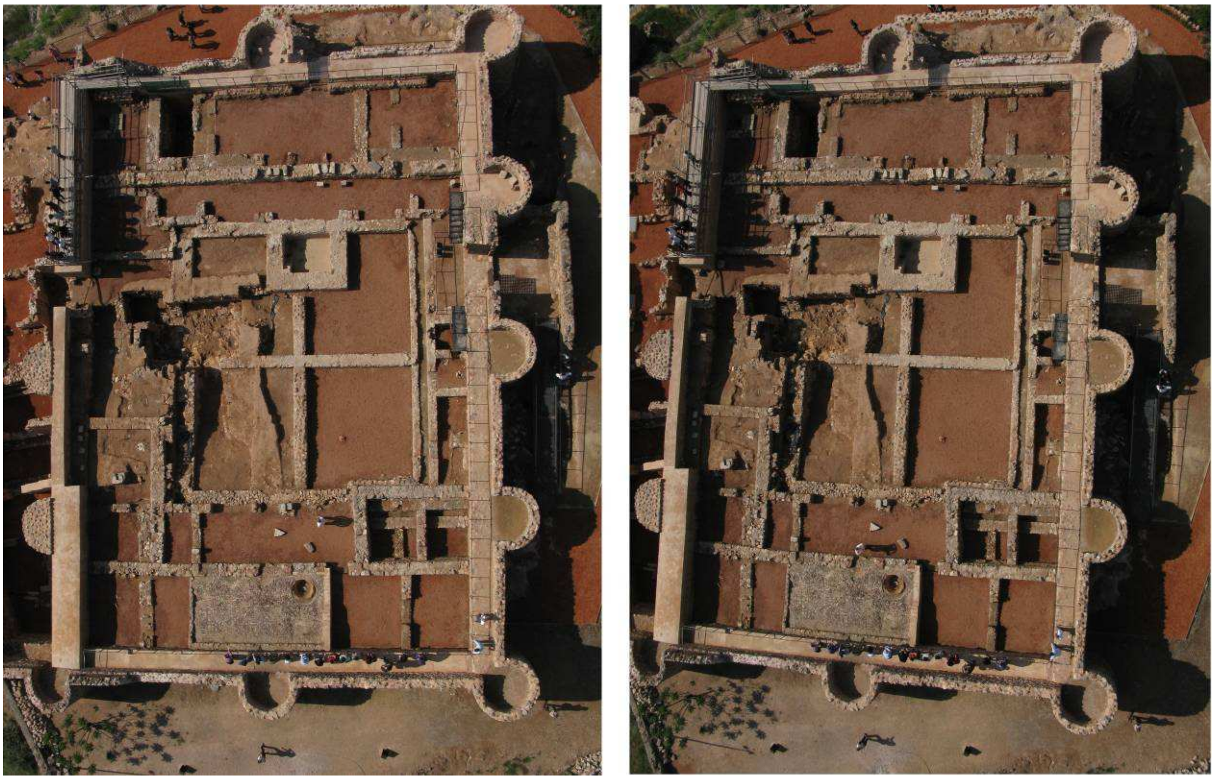

Figure 3: Onda Castle. Stereo pair of the Onda Islamic Palace.

Figure 4: Balloon, tilt and pan cradle, camera and control lines.

The advantages of this technique are obvious, very low cost, high quality, easy to obtain aerial images. Further advantages include the creation of 3D models and measurements from the photogrammetric data. The main disadvantages are that in many locations helium is extremely expensive or unobtainable and with any significant wind the balloon becomes uncontrollable. In many sites the wind is absent early in the morning, therefore, the optimum time to launch a balloon. However, this is a disadvantage for capturing photogrammetric stereo pairs, as the best time to capture these images is after midday when the shadows are not as severe. An additional disadvantage is that there are many governments that restrict the use of such techniques; a four meter diameter white balloon with a camera attracts attention. The resultant images and photogrammetric data will be used before a new campaign of excavations begin at the site in the summer of 2011, Figure 3.

1.4 Kite Photography

One of the most difficult aspects that the investigators discovered while working with balloon photography was that balloons are extremely difficult to control in winds above 4 km per hour. This lead directly to investigating a substitute for the balloon as a lifting mechanism. Kite aerial photography (KAP) has been around for many decades and there is a wealth of material available[9]. Like other techniques it deserves a review as cameras and software have improved and can be easily compared with other techniques. During the summer of 2010 the investigators documented Los Angeles' beach lifeguard towers. Part of the Portraits of Hope Initiative, the Summer of Color involved 6,000 children from schools, hospitals and social service programs to paint panels that were installed on the roofs, walls and doors of the lifeguard structures[10], Figure 5.

Figure 5: Navy Street Life Guard Tower. Photographed with KAP and a Nikon D60 camera.

Several different types of kites, cameras, lenses, control systems and mounting platforms were investigated and tested in order to capture images of the towers. This proved to be a very successful technique because the camera could be safely positioned very close to the towers and the wind was constant. Because winds are variable, kite lifting platforms must also be variable. Therefore, for this investigation a variety of kite types were tested. A large 2-meter delta kite, Levitation Delta Light, with a carbon fiber frame for lightwinds (3 to 6 km per hour), and two parafoil kites without internal structures a Sutton Flowform 30 with a 3 square meter wing and small Sutton Flowform 16. Various camera cradles and cameras were also tested, from simple plastic L brackets to radio remote control pan and tilt kit systems, Figure 6. This technique was also used successfully at Onda when the winds from the Mediterranean began to increase toward midday and the balloon became unstable.

Figure 6: Remote control pan / tilt camera cradle suspended from kite line.

Advantages of KAP include low cost, the ability to lift fairly heavy payloads, and it is a direct substitute for balloon photography as most of the hardware and software can be used on either system. Another unforseen advantage is that images can often be captured without detection or disruption. The main disadvantage is, of course, there must be semi steady winds over 4 kilometers per hour and in highly variable winds landing the camera safely proved challenging. Another disadvantage discovered is that there is an upper wind limit at approximately 30 km per hour, thus controling and landing the kite at these wind speeds proved difficult. KAP also requires open space to launch and practice was essential. In addition, a variety of kites, cameras and camera cradles must be available for varying wind conditions making this technique slightly more expensive than balloon photography. Other drawback include difficulities in obtaining smooth video and suitable stereo pair images for photogrammetry.

1.5 Multicopter and fixed-wing aircraft

The final tools to be investigated and evaluated were remote control multi-copters and fixed and flexible wing model aircraft, Figures 7 and 8. Remote control helicopter and fixed wing photography are some of the more complicated forms of aerial photography[11]. Extensive training was needed to construct and fly these devices and costs can range from $500 into the thousands. Professional off the shelf systems are available but these can cost tens of thousands of dollars. Additional drawbacks include limited altitude/fly time for helicopters or other aircraft operating on batteries and very strict government permission requirements. However, these forms of aerial photography are becoming more reliable and offer greater control. A multicopter offers a better, smoother platform for video while a fixed or flexible wing model aircraft is good for creating overlapping images of large sites for the creation of site plans. The multirotor helicopter also can be good for horizontal photography inside large structures. These devices are currently in the testing phase and have been flown with some aerial images captured and a case study is currently underway.

Figure 7: Four rotor multicopter. Camera tilt and pan cradle below suspended on elastic straps.

Figure 8: Fixed wing foam airplane with electric pusher motor and camera.

2. FURTHER INVESTIGATION, EDUCATION

In addition to the testing of powered flight vehicles such as multicopters and fixed-wing airplanes further investigation includes alternative lifting mechanisms. One of the major drawbacks that became apparent during the use of balloons was that helium is not always available or affordable in developing countries, this lead to researching hydrogen and hot air balloons. Hydrogen was quickly dismissed due to flammability, but hot air as a lifting mechanism shows promise. Propane as a means to heat the air is readily available in almost all countries and very affordable. In addition, all the techniques and tools used for helium are directly transferable. Flame retardant rip stop nylon used to construct hot air balloons and CAD drawing patterns have been obtained by the investigators and it is the intention to continue development for operation by mid 2012.

Another platform that is being investigated is the construction of a flexible Rogallo wing remote control aircraft[12]. This is essentially combining a kite with a powered airplane. The large wing surface should provide greater lifting capacity, slower forward flight speed, easier control and extended flight time in addition to a foldable, portable wing. A Rogallo wing system is currently under construction by the investigators. It is also in the longer term goals of the investigators to make the powered flight vehicles autonomous or semi autonomous. This would allow the user greater control and ease of use, one of the main disadvantages to powered flight. In addition to investigating alternative lifting systems it is a priority to continue testing and improving existing tools and techniques. One major improvement is the use of gyro stabilized camera mounts. This would aide in stabilizing the camera and possibly lowering shutter speeds or in obtaining video. Another improvement planned for the existing systems is the use of GPS for tracking movements and camera position.

With all these investigations it has always been a priority to involve the training of architects or conservators in these techniques. In January, 2011a key training session was held at the Raymond Lemaire International Centre for Conservation (RLICCC) at Katholieke Universiteit Leuven, in Belgium. Over 30 architectural conservation students were involved in the recording of the complex roof structure of the castle of Arenberg and this was very useful to assess roof condition and decay, Figure 9. Furthermore, the images captured by this technique could potentially be useful with recent developments in computer graphics that permit the generation of three-dimensional models from un-calibrated photographs (i.e. Photosynth, Arc 3D Webservice).

Figure 9: Complex roof structure of the Castle of Arenberg.

3. CONCLUSION

In conclusion, the view from above gives a unique perspective and powerful tool to document and record cultural heritage. With these aerial photographic techniques more data can be collected at a faster rate over a wider area at a lower cost than other ground based methods. Recent advance in higher resolution yet less expensive cameras, higher capacity memory chips, and operating and post processing software have made these aerial techniques more available and affordable than ever before. In addition, many of the more advanced techniques such as multicopters and fixed-wing aircraft are also becoming easier to use and approachable as dedicated enthusiasts around the world work and share ideas. The techniques that have been investigated thus far are only just a beginning and the search for simple, reliable and low cost aerial photography systems will continue. It is the opinion of the investigators that all of these techniques should continue to be investigated and shared with the conservation and documentation communities. Also, that all techniques must be periodically reevaluated and tested in as many different situations as possible as technology continues to evolve.

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