

Precise Dynamic Measurement of Structures Automatically Utilizing Adaptive Targeting

Gary Robertson
ShapeQuest Inc. Ottawa, Canada
gary@shapecapture.com

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ABSTRACT:

This paper describes a procedure to measure to high accuracy large and small structures in a static or dynamic state. The process utilizes alternative light to create a specific excitation wave length and resolving emission wavelength. This form of targeting is very efficient and unlike laser is non-resonant. This opens a very important area in photogrammetric measurement since it allows for precise automated measurement regardless of distance constraints, atmospheric or lighting conditions at time of measurement.

1. INTRODUCTION

1.1 Background:

Photogrammetry has over the years been used widely in the areas of precise measurement in areas of aerospace and structures including structural deformation analysis. The scope of this analysis has been more on static measurements of well defined control and targeted points. With the development of automated target measurement (Robertson, Wyatt 1984) greater accuracy can be achieved for static measurement. The dynamic measurement of structures presents some problems in cameras or image synchronization and the correct targeting approach. (Robertson 2002). The targeting was either retro reflective or projected light targeting. Both methods work well for automated measurement but are restricted to application areas of smaller objects and restrictive environmental situations.

Research into the use of LEDs (light emitting diodes) especially with Gallium Indium Nitride in the areas of ALS (Alternate Light Source) (Robertson 1998, 2000) in the fields of forensics led us to look at and develop the adaptive targeting approach.

1.2 Development Phase of Adaptive Targeting:

The research was based upon developing a targeting system to meet the following criteria,

- ✓ To be used in various type of environmental conditions.
- ✓ Allow the target to be seen from a few meters or perhaps hundreds of meters.
- ✓ The targets must be stable and sustain high G forces or severe vibration.
- ✓ Targets must be able to be set at specific excitation wave length and resolving emission wavelengths for use with the ShapeMonitor system.
- ✓ The ability to create a near binary target array.
- ✓ Have the ability to turn on and off at a fast rate.
- ✓ Ability to be viewed at wide viewing angles.

Looking at the basic parameters would rule out Incandescent or Neon bulbs or even laser so we focused on the use of Light-Emitting Diodes (LEDs).

Unlike lasers, LEDs are non-resonant and can be made to emit at any color in the spectrum. LEDs are also very color stable especially in spectral bandwidth and have a long life of about 20,000 hours.

The LEDs are a factor of ten times more efficient than a laser or filtered incandescent source, this means that lower power requirements are required. Also the LEDs can be rapidly turned off and on in less than a millionth of a second, this offers substantial advantageous for our applications.

The efficiency of the LEDs in terms of lumens per watt output depends on the colour. Colours towards the red end of the spectrum will have a larger light output than those at the blue end. Typically, a 1 watt white LED has a light output of 25 lumens per watt.

LEDs do not emit light uniformly in all directions, dropping in luminous intensity as a viewer moves away from a direct or on-axis vantage point. The half-intensity beam angle, given in degrees, is used to characterize how far in degrees from the on-axis perspective a particular LED's luminous intensity drops to 50 percent. An example of this would be two LEDs with equal luminous intensity, the LED with a half-intensity beam angle of 40 degrees provides a wider viewing angle than the LED with a half-intensity beam angle of only 20 degrees. This is true even though both may generate the same amount of total light for a given supply current.

Tests were made to determine the correct diffusing material and color. Factors that contribute to viewing angle include the amount of diffusant the shape of the reflector cup which surrounds the LED chip, the shape of the LED lens, and the distance from the LED to the nose of the lens. When there is no diffusant, the viewing angle is ± 10 to 12 degrees it can be up to ± 70 degrees when the maximum amount of diffusant is employed. An example of this can be seen in Figure 1.



Figure 1. LED array 0-15 degrees



Figure 2. LED array 15-30 degrees

For photogrammetric applications we require a target to provide us with a bright consistent illumination over the widest possible field of view. Numerous tests were made as to color, and lens design. Additional testing was undertaken to test for wavelength, and to look at custom filtering to adapt to the cameras. The specific excitation wave length and resolving emission wavelength must be very close as to allow for a very narrow bandwidth this would block out all light and only allow a fixed bandwidth to be seen by the image sensor. This allows us to have a binary image even in bright sunlight conditions. The individual LED arrays then had to be custom assembled into a wired resistor target array with its own individualized power sources.

2.0 MEASUREMENT SYSTEM

The ShapeMonitor measurement system initially had been described by (Robertson 2002) it comprises both software and hardware components to allow measurement either in static and dynamic modes or at near real-time rates. The system utilizes dual 2.0 mega pixel digital cameras with 30 frames per second frame rates. To sustain these data rates the computer is custom configured with high speed disk arrays synchronized by custom computer hardware and software. The system will support multiple camera units. The system was designed for real-time measurement, but will also work in offline batch processing of data.



Figure 3. ShapeMonitor system with 2 of the 4 cameras with filters on lenses

2.1 Automated Measurement

The target stereo matching principal used in ShapeCapture and ShapeMonitor software is based on epipolar geometry as shown in Figure 4. Please note: this is used for the targeted points only and different from the absolute stereo matching process just introduced.

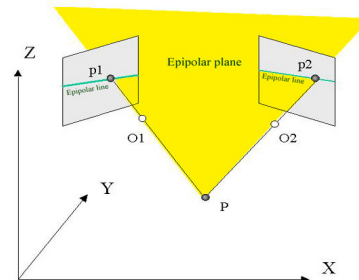


Figure 4 Epipolar Model

The object point P, the two projection centers of the two images, O1 and O2, form a plane (the epipolar plane) that intersects the two image planes. As a result, two epipolar lines are created. The matched points fall on these lines. Once the camera positions and orientations at the two image locations are known, the equations of the epipolar lines become known. We will now start by taking the coordinate p1 in the left image and

look for point p2 on the epipolar line in the right image. Since there could be other points falling on the same line, we need additional constraint to make sure we select the appropriate point. The system allows for multiple systems to be integrated together for monitoring dynamic events. The system can also incorporate cameras with higher frame rates (hundred of frames per second)

3.0 DYNAMIC ADAPTIVE TARGET TEST

The Adaptive targeting research testing was made at the University of California, San Diego Englekirk Center Powell Structural Research Laboratories. These facilities provide large-scale seismic safety tests of buildings and bridges. For our test The LEDs target arrays were anchored to a 7 story building in designated locations and wired to several system power supplies prepared for the targets.

The structure was built on the facilities Outdoor Shake Table the worlds first outdoor shake table, it measures 7.6m wide by 12.2m long single DOF system with the capability of upgrading to 6-DOF. The specifications for the first phase of the facility are a stroke of $\pm 0.75\text{m}$, a peak horizontal velocity of 1.8 m/s, a horizontal force capacity of 6.8MN, an overturning moment capacity of 50MN-m for a 400 ton specimen, and a vertical payload capacity of 20MN. The testing frequency range will be 0-20 Hz.

Although this table is not the largest of its kind in terms of size in the world, the velocity, frequency range, and stroke capabilities make it the largest table outside Japan and the world's first outdoor shake table. It has no overhead space and lifting constraints.



Figure 5. Building with target arrays powered on



Figure 6. Close up view of adaptive target arrays powered on



Figure 7. Image with camera fitted with filter that resolves the emission wavelength

The required accuracy for the test was in the range of 1 mm. Due to locations of the target array on the structure 2 ShapeMonitor systems were used, one system for the upper section the second would be used for the lower section as shown in Figure 8 and 9.



Figure 8. Layout of system



Figure 9.

The filters for the cameras were calibrated and indexed for the particular lens mounted on the body using the calibration template fixture shown in Figure 10. The testing of the targets was to be made while the structure was in slight motion (white noise test) of the shake table. The capability to measure the structure dynamically requires that the cameras be synchronized to the sub pixel. The building and the shake table is wired for a

complex monitoring system such as transducers and actuators that monitor reactions and movements of the table and the structure itself. It was requested that the photogrammetric system be linked with the structure and the shake table system. For this to happen, the 2 ShapeMonitor systems with 4-2 mega pixel cameras needed to start at the instant the table was activated and be linked to the sites data recording system. In addition to this we had to ensure that the 4 cameras maintained the pixel clock locking. This interfaced required a custom hardware interface, cabling and software. This would enable us to link and compare data sets between the photogrammetry and transducer data sets.

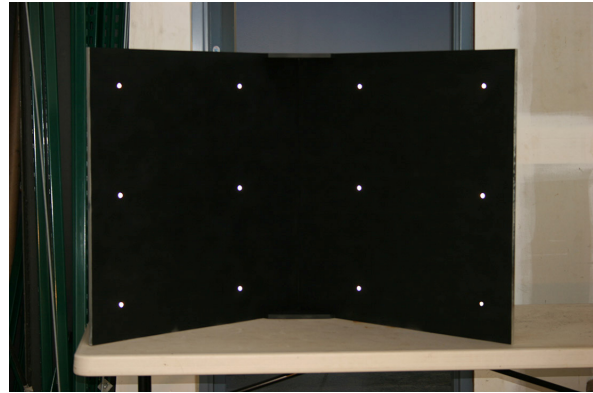


Figure 10.

In addition to the accuracy of 1 mm the dynamic event cycle was to be for 2 minutes in length. Even with the specially configured computers with a raid array of 5 disk drives per camera it would be pushing a lot of data to the system. For this reason the data was to be post processed. Additional testing was made, one was to ensure that the system would not drop frames during the 3600 frames over the 2 minutes. Some of the tests showed a few frames were dropped other times they were not. We enabled in the software a technique to time code the dropped frame sequences to enable us to locate the data in the recorded data sets.

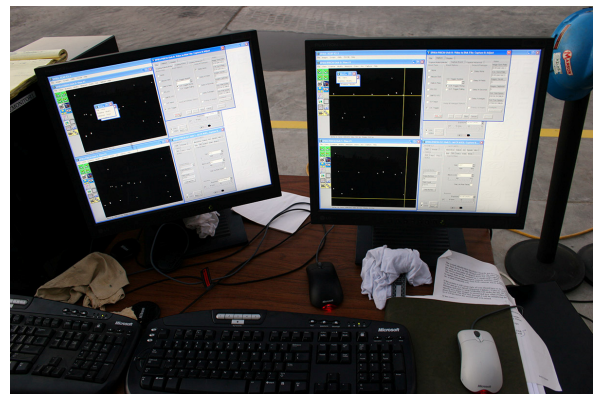


Figure 11. System screens showing the binary data sets from the filtered cameras.

Additional research was undertaken regarding timing, we placed a LED array in the field of view of the cameras and the structure. This LED array would be triggered with the same modified circuit wiring that would activate the ShapeMonitor

system and the Shake table. This was to test the fast start up of the LEDS and to check with the correlation between the systems. Figure 12 and 13 show a model of 2 images obtained from upper and lower cameras.

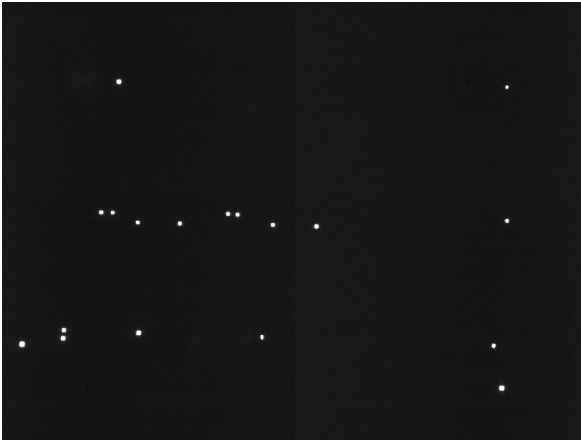


Figure 12. upper image pair

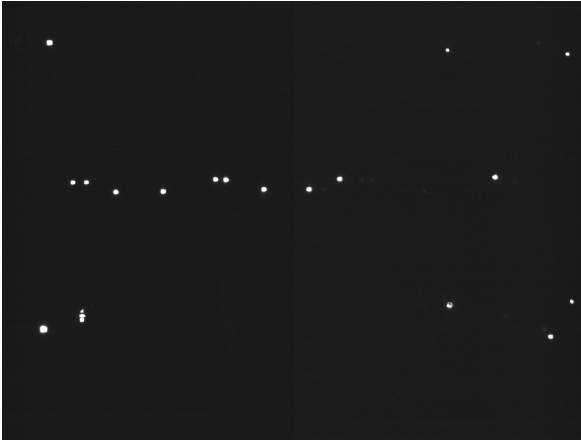


Figure 13. Lower image pair

Control points were surveyed and were part of the target array system, before each test a survey was made.

Prior to the system receiving a system start command, a set of frames are obtained, this is used for the registration of the system. The 2 ShapeMonitor systems are then armed and await the command via cable interface from the command center. The system once registered can then start processing the data. During the registration process you select the window, and the target parameters. You simply select the number of models to be tracked in this case 3,600 and select the processing time interval between models in this case was 1 second. The entire process is then automated and the 3,600 model coordinate sets are computed and saved in the individual frame coded file with the 1 second per model.

4.0 DISCUSSION OF RESULTS:

This was an excellent test for the Adaptive LED targeting. The building was illuminated with full frontal sunlight and the specific excitation wave length and resolving emission wavelength worked to provide a narrow bandwidth to create binary data images for measurement. This also expands the use of our system for monitoring dynamic events with large structures in any type of lighting up to long distances. It also avoided the use of retro reflective or projected light targeting. The testing also showed how photogrammetry systems can interface to existing monitoring systems.

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5.1 REFERENCE

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