Low-cost & Effective 3D Geometric Reconstructions of Targets at Macroscopic Scale

Timothy Bauch, Carl Salvaggio, Roger Easton, Jim Ferwerda
Carlson Center for Imaging Science- Rochester Institute of Technology

Abstract

When an artist creates a painting there are always concerns over being able to properly protect the authenticity of their work. Counterfeiters may try to replicate the artwork and claim it as genuine. If an artist can accurately ascertain the surface topography of their artwork, they will be able to win any legal dispute of the authenticity of such work. There are currently many methods with which they may be able to properly image and protect their artwork. High-resolution, topographic detailing usually carries a high cost and may not be economically feasible for the average artist. This paper proposes a low cost, portable, and easy to use system that an artist, or other practitioner, may be able to use in order to measure surface structure on their paintings, currency, or other documents in order to protect its authenticity. Through the combination of a computerized numerical controlled (CNC) machine with a common DSLR camera we have been able to put together a low-cost system that will give us all the data necessary for 3D surface reconstruction. This data can then be sent into any structure-from-motion photogrammetry software program on the market and produce an accurate model of the surface at a fraction of the cost of many other high-end surface-topography systems. This device has shown promise as a prototype off the shelf imaging system with a high degree of accuracy for the relatively low price point of the system.

Graphical User Interface (GUI)

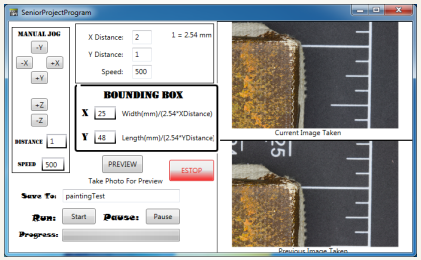


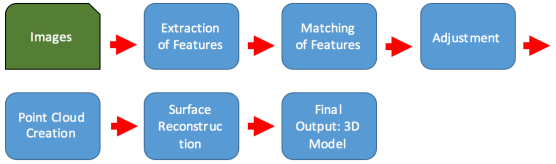
Fig 1. GUI created to facilitate the controls of the CNC machine, as well as, the scanning process to capture images

Controls

The Graphical User Interface (GUI) gives the user complete control of all movements needed, on the CNC machine, to collect data using the structure-from-motion technique.

- ***X & Y Distance*** enables the movements in both directions to be set accordingly to achieve proper overlap desired.
- ***Manual Jog*** allows user to properly align camera before operating.
- ***Bounding Box*** sets the amount of movements in X and Y directions to scan over entire surface area.
- ***Preview*** button allows the user to view an image, before the scan begins, to ensure proper image exposure, zoom, focus etc.
- ***Save To*** gives the user the ability to choose where the images are being saved to for later processing.
- ***Images,*** seen on the far right of the GUI, are for the user to see current and previous images being captured to ensure no capturing errors.

Structure-from-Motion



- Multiple overlapping photographs
- Features extracted from data
- 3-Dimensional reconstruction algorithm

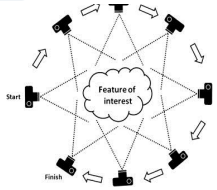


Fig 2. The SfM technique requires multiple images with a high percentage of overlap for input.

System Components

Being able to produce a relatively inexpensive system can be quite challenging when combining the different processes necessary to automate the structure-from-motion technique. The first essential element is a camera that can produce high-resolution images. The camera would most likely require a macro lens which is able to resolve fine detail of surfaces for close range targets. The next element is a machine that is capable of moving in a controlled manner through Cartesian spaces. Having these two components the last component would be developing software for a user to control both of the other components with relative ease. The main goal therefore, was to be able to achieve these subtasks while maintaining an affordable cost for an average user such as an artist.

System Price List

1) Canon T2i DSLR camera ~$299
2) Canon 60 mm Macro Lens ~$399
3) Illuminating ring ~$99
4) Probotix Fireball V90 ~$1,999
5) Camera mounting brackets ~$140

Total: $2,940.00

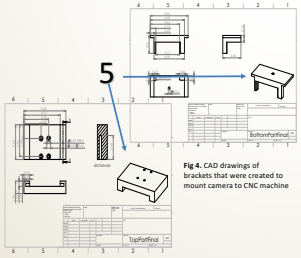
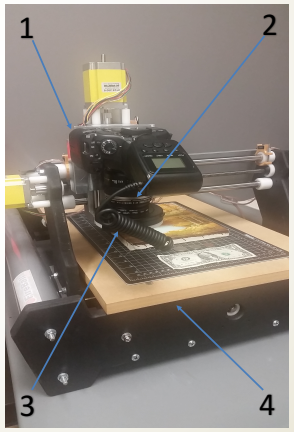


Fig 4. CAD drawings of brackets that were created to mount camera to CNC machine



Results

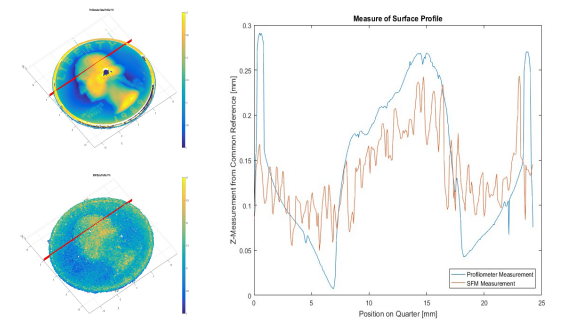


Fig 3. Results comparing topographic data from a high-end profilometer, top left, and the low-cost system proposed in this research, bottom left..

Table I: Accuracy Results

Error in Z (Depth)	
RMSE	57.1 μm
Percent Difference	18.7 %

- Figure 3 shows data compared from a profilometer and our proposed system.
- We can tell that the profilometer data has less noise than the proposed system does.
- Data shows that our system can generate a reconstruction that holds close to a system that costs over $50,000.
- Table IV shows that the accuracy is within an average of 57 microns RMSE over the length of the slice processed.

Conclusion

The goal at the end of this experiment was to design and implement an imaging system that would be low-cost and effective in reconstructing a 3D model of an object. Making use of a CNC machine, that was available to us, we were able to make use of an API in order to control movements. We also designed a bracket to attach a camera to the CNC machine, in order to capture images using the technique of Structure from Motion. The final achievement was creating an easy to use GUI to allow anyone to properly control the system. In the end, we were able to achieve this goal by creating a system that is under $3,000 while holding close to the accuracy of other high-cost systems. Our accuracy measurements were within 50-60 microns of a high-end measurement device, such as a profilometer.

Contact

Timothy Bauch
RIT Imaging Science Dep.
Email: tdb8904@rit.edu

References

1. Westoby, M. J., Brasington, J., Glasser, N. F., Hambrey, M. J., & Reynolds, J. M. (2012). 'Structure-from-Motion'photogrammetry: A low-cost, effective tool for geoscience applications. Geomorphology, 179, 300-314.
2. Fonstad, Mark A., et al. "Topographic structure from motion: a new development in photogrammetric measurement." Earth Surface Processes and Landforms 38.4 (2013): 421-430.
3. Nilosek, David R.; Walvoord, Derek J.; Salvaggio, Carl, Assessing geoaccuracy of structure from motion point clouds from long-range image collections, Optical Engineering, 53, 11, pp. 113112-1-113112-10 (November 2014).
4. Sayles, R. S., & Thomas, T. R. (1978). Surface topography as a nonstationary random process.
5. Valentino, J., & Goldenberg, J. (2003). Introduction to computer numerical control (CNC). Englewood Cliffs: Prentice Hall.
6. Perone, C. S. (2009). Pyevolve: a Python open-source framework for genetic algorithms. ACM SIGEVOlution, 4(1), 12-20.
7. Koenderink, J. J., & Van Doorn, A. J. (1991). Affine structure from motion. JOSA A, 8(2), 377-385.
8. Faugeras, O. D., & Lustman, F. (1988). Motion and structure from motion in a piecewise planar environment. International Journal of Pattern Recognition and Artificial Intelligence, 2(03), 485-508
9. Stout, K. J., & Blunt, L. (2000). Three dimensional surface topography. Elsevier.