Journal of Applied Mechanical Engineering

Zhang and Huang, J Appl Mech Eng 2012, 2:1
DOI: 10.4172/2168-9873.1000e111

Editorial Open Access

3D Surface Shape Measurement based on Fringe Projection Techniques

Zonghua Zhang* and Shujun Huang

School of Mechanical Engineering, Hebei University of Technology, Tianjin 300130, China

Optical full-field fringe-projection-based 3D measurement techniques have been widely studied in academia and applied to industrial fields such as automated inspection, reverse engineering, cosmetic surgery and so on owing to the advantages of non-contact operation, fast acquisition, high precision and automatic data processing [1-6]. One or a series of fringe patterns are projected onto the surface of measured objects. From a different viewpoint, the fringe patterns are deformed with respect to the measured shape and an imaging device captures and saves the deformed fringe patterns for post processing. The phase information modulated in the deformed fringe patterns corresponds to the depth (shape) of the measured object and can be calculated mostly by the Fourier transform [7], Wavelet transform [8] or phase stepping algorithms [9] and then unwrapped to obtain absolute phase data. The obtained phase needs to be converted into depth data by a procedure called as calibration, which builds up the relation between phase and depth [10].

Existing fringe-projection-based 3D measurement systems mostly utilize evenly spaced fringes at the projecting device which can be formed using either a Ronchi ruling, grating or computer generated fringe pattern image. Non-telecentric lenses are mostly used on both the imaging and projecting devices to provide flexibility over the object size and field of view. The non-parallel axes of the imaging device and projecting device, necessary for triangulation, create variable period fringes across a plane orthogonal to the imaging axis. Therefore, the phase to depth relation is nonlinear and dependent of x and y-coordinates of the imaging system [10]. A number of researchers have studied the relation between phase, depth, the systematic parameters and x, y-coordinates (pixel position when the imaging device is a CCD camera) [10-14].

Based on the mathematical relation of phase, depth, the systematic parameters and x, y-coordinates, one approach is to estimate the systematic parameters. This may be achieved using multi-parameter minimization or least-square methods; however, the object depth calculation depends on the x coordinate in the image. To correct for the non-linear relation, some alternative neural network approaches have been studied, using for example, radial basis functions, multi-layer perceptron, Bernstein basis functions and feed-forward back-propagation configurations [15-19]. Neural networks offer the potential to accommodate deviations from the ideal mathematical relations, e.g. due to lens distortions. However, neural networks-based methods require considerable sets of training data to be generated to define the relation between the input parameters and the desired object depth at adequate resolution.

With the advent of color CCD cameras and DMD (Digital Micromirror Device) based color DLP (Digital Light Processing) projectors [20], the fringe patterns are generated by programming in a software and sent out by a DLP projector. Therefore, the programmed fringe patterns can have variable periods in between to give evenly spaced fringes within the measurement volume with a constant period on a plane orthogonal to the imaging axis, which called as an uneven fringe projection technique [21]. The relation between phase and depth becomes a simple linear function, independent of the pixel position. This means the relation is the same at all the pixel position in principle without considering lens distortion. It is possible to calibrate the uneven fringe projection system by using several discrete points with known phase and depth data in the measurement volume.

Another application of color CCD cameras and color DLP projectors is to code fringe patterns into the red, green and blue channels of a color image to measure colorful objects [22] or reduce the acquired numbers of fringe pattern images [23,24]. By comparing the fringe modulation depth between color channels, phase information at each pixel is determined from one color channel having the maximum modulation depth value. Color information of the object surface is also calculated with high dynamic range from the same captured color fringe patterns [22]. When three fringe patterns are coded into the three color channels of a composite RGB image, they can be simultaneously projected onto the measured object surface. Therefore, the acquired numbers of images reduce to 1/3 in comparison to gray fringe projection technique [23, 24].

With the rapid development of MEMS (Micro Electro Mechanical Systems), micro fluidics and the micro moldings industries, there are great demands for on-line inspection of the surface quality by using their 3D CAD design data. Another future direction is to measure shape of big manufactured parts, for example, airplane body and ship hull. Existing methods to inspect 3D discontinuous structure and surface shape need long data acquisition time and the calibration procedures are complicated. Therefore, there are many challenging unsolved problems to the digital fringe projection method for fast measuring 3D surface shape of objects with large slopes and/or discontinuities.

References

1. Zhang ZH (2012) Review of single-shot 3D shape measurement by phase calculation-based fringe projection techniques. Opt Lasers Eng 50: 1097-1106.
2. Chen F, Brown GM, Song M (2000) Overview of three-dimensional shape measurement using optical methods. Opt Eng 39: 10-22.
3. Talapov A, Roberson T, Lebedev A, zhilyaev A, polonskiy L (1998) Optical 3D digitizers: bringing life to the virtual world. IEEE Comput Graph Appl 18: 28-37.
4. Salvi J, Fernandez S, Pribanic T, Llado X (2010) A state of the art in structured light patterns for surface profilometry. Pattern Recogn 43: 2666–2680.
5. Blais F (2004) Review of 20 years of range sensor development. J Electron Imaging 13: 231-240.
6. Gorthi SS, Rastogi P (2010) Fringe projection techniques: Whither we are?. Opt Lasers Eng 48:133-140.
7. Takeda M, Mutoh K (1983) Fourier transform profilometry for the automatic measurement of 3D object shapes. Appl Opt 22: 3977-3982.

***Corresponding author:** Zonghua Zhang, School of Mechanical Engineering, Hebei University of Technology, Tianjin 300130, China, E-mail: hzhangtju@hotmail.com, zhzhang@hebut.edu.cn

Received October 23, 2012; **Accepted** October 25, 2012; **Published** October 29, 2012

Citation: Zhang Z, Huang S (2012) 3D Surface Shape Measurement based on Fringe Projection Techniques. J Appl Mech Eng 2:e111. doi:10.4172/2168-9873.1000e111

8. Zhang Z, Jing Z, Wang Z, Kuang D (2012) Comparison of Fourier transform, windowed Fourier transform, and wavelet transform methods for phase calculation at discontinuities in fringe projection profilometry. Opt Lasers Eng 50: 1152-1160.

9. Katherine Creath (1988) Phase measurement interferometry techniques, Progress in Optics XXVI, North Holland Publ, Amsterdam.

10. Zhang Z, Zhang D, Peng X (2004) Performance analysis of a 3D full-field sensor based on fringe projection. Opt Lasers Eng 42: 341-353.

11. Chen L, Quan C (2006) Fringe projection profilometry with nonparallel illumination: a least-squares approach. Opt Lett 30: 2101-2103.

12. Rajoub BA, Burton DR, Lalor MJ (2005) A new phase-to-height model for measuring object shape using collimated projections of structured light. J Opt A: Pure Appl Opt 7: s368-s375.

13. Guo H, He H, Yu Y, Chen M (2005) Least-squares calibration method for fringe projection profilometry. Opt Eng 44: 033603.

14. Zhang Z, Ma H, Zhang S, Guo T, Towers CE and et al (2011) Simple calibration of a phase-based 3D imaging system based on uneven fringe projection. Opt Lett 36: 627-629.

15. Cuevas FJ, Servin M, Rodriguez-Vera, R (1999) Depth object recovery using radial basis functions. Opt Commun 163: 270-277.

16. Cuevas FJ, Servin M, Stavroudis ON (2000) Multi-layer neural network applied to phase and depth recovery from fringe patterns. Opt Commun 181: 239-259.

17. Dinesh G, Joby J, Kehar S (2002) Profilometry for the measurement of three-dimensional object shape using radial basis function, and multi-layer perception neural networks. Opt Commun 209: 291-301.

18. Ganotra D, Joseph J, Singh K (2004) Object reconstruction in multilayer neural network based profilometry using grating structure comprising two regions with different spatial periods. Opt Lasers Eng 42: 179-192.

19. Knopf GK, Kofman J (2002) Surface reconstruction using neural network mapping of range-sensor images to object space. J Electron Imaging 11: 187-194.

20. Younse J M (1993) Mirrors on a chip. IEEE Spectrum 30: 27-31.

21. Zhang Z, Towers CE, Towers DP (2007) Uneven Fringe Projection for Efficient Calibration in High Resolution 3-D Shape Metrology. Appl Opt 46: 6113-6119.

22. Zhang Z, Towers CE, Towers DP (2012) Robust colour and shape measurement of full colour artefacts by RGB fringe projection. Opt Eng 51: 021109.

23. Zhang Z, Towers CE, Towers DP (2006) Time efficient color fringe projection system for 3D shape and color using optimum 3-frequency selection. Opt Express 14: 6444-6455.

24. Zhang Z, Towers Dp, Towers CE (2010) Snapshot color fringe projection for absolute three-dimensional metrology of video sequences. Appl Optics 49: 5947-5953.