DEFINITION OF THE OPERATIONAL PARAMETERS OF A STRUCTURED LIGHT SYSTEM AND DEVELOPMENT OF AN ADAPTIVE LIGHTING ALGORITHM

Prof. Casavola C PhD, Dr. Pappalardi P M.Sc., Dr. Pappalettera G. Phd
Dipartimento di Meccanica, Matematica e Management, Politecnico di Bari, Italy

giovanni.pappalettera@poliba.it

Abstract: *Surface 3D reconstruction a topic of great relevance and having a wide range of applications. Systems for surface contouring can be divided into two main categories: the contact systems and non-contacting systems. CMM is the most widespread contact methodology while the 3D laser scanner is the most popular without contact approach. Nowadays further systems are under study and development. One of the most promising is the Structured Light Projection (SLP) approach based upon the projection of a complex pattern of light on the object to be reconstructed. The projection determines the distortion of the projected pattern, the modulated pattern contains the information about the object geometry. If compared with laser scanning SLP is very effective to reduce the measurement time as it does not require the operation of scanning of the object. Also it becomes of great importance when the measurement has to be done on very complex shape object. In fact, in this case, proper identification of the projected sequence can allow to manage very high discontinuity. This becomes essential, for example, in the case of contouring of cultural heritage artifact. For this class of object, moreover, structuration in terms of light intensity could be adopted to compensate local variation of reflectivity. In this paper operating parameters of a structured light system are defined. In particular, the optimal frequency of the projection pattern was defined. Furthermore an algorithm is proposed that locally controls the level of illumination to compensate for the local inhomogeneities in terms of surface reflectivity.*

Keywords: FRINGE PROJECTION, STRUCTURED LIGHT SYSTEM, SURFACE CONTOURING, SURFACE REFLECTIVITY.

1. *Introduction*

In recent years, the production of digital models of real objects is becoming very important in different areas such as mechanical design, dimensional control, quality control, industrial design, bioengineering and the protection of cultural heritage. Reverse Engineering, allows obtaining, as a final output, a file representing a digital copy of the object manageable by modern CAD / CAM software. The shape acquisition systems can be divided into two types [1]: the contact techniques and non-contact techniques. The former have an accuracy that can reach up to 0.5μm to be compared with 10μm usually achievable by optical technologies [2]. This difference mainly depends on the fact that, in the firs case, the detection is performed touching the surface point by point, then the process is very complex and is characterized by low data acquisition speed. Although no-contact techniques they cannot be applied on soft or brittle objects. The non-contact techniques, based on optical technology, are mostly used due to high speed of acquisition coupled with excellent accuracy. The optical techniques can be divided into two types, depending on the mode of interaction with the physical shape of the object and the type of light source used. The first strategy, known as passive optical acquisition, tries to analyze the 3D scene under ambient light. The most widespread is the photogrammetry that allows obtaining high levels of accuracy but it requires long times for the data processing and the delicate operation of the system calibration [3]. The second one, known as active optical acquisition, tries to reduce the ambiguity of analysis of the scene with the addition of projections in the measurement area. The second strategy can be further divided in punctiform or full-field measure. In the first case the most common technique is the laser scanner which, while guaranteeing good accuracies, requires long measurement times associated with the operation of scanning of the object. Among the optical active full-field acquisition techniques the most promising is the Structured Light System. This technique ensures high accuracy, even on complex shapes. The acquisition times are reduced, being able to acquire a large amount of points per second, and has a very wide applicability. However in addition to require post-processing operations, while capturing you may have undesirable effects that amplify noise and optical noise as the interference of light in the environment caused by absorption or excessive dispersion of the reflected light.

2. *Structured Light System*

The major application of SLS are in industrial (Reverse Engineering, Rapid Prototyping, Quality Control), medical and dental, and in addition to cataloging and restoration of cultural heritage [2]. It is an active optical technique in which a light pattern is projected over the surface of the object and one CCD camera is adopted to detect light reflected by the object. Appropriately demodulating the information it is possible to extract the shape of the examined object, creating a unique match between the image pixels and the points analyzed in the physical space. The determination of the coordinates of the surface of an object is obtained through the *Triangulation* method [4]. There are various types of patterns; the faster one, common and versatile involves the projection of a number of light stripes at the same time, horizontal or vertical, generated with a projective method. The accuracy of the technique is a function of the pattern and frequency of the calibration techniques adopted [3]. It is also possible to increase the quality of the measurement using the technique called *Phase Shifting*, which involves the projection of fringes which are shifted by given phase value. It is possible to improve the detail of the surface by increasing the number of such positions, without varying the frequency of the pattern. Accuracy of the measurement can be increased by proper calibration taking into account lens aberation [5]. An important step in the process measurement is the phase determination of the recorded pattern. . This can be done by *Fourier Transform* [7] and *Temporal Phase-Shifting* [8]. This operations leads to the so-called wrapped phase where all the phase values belongs to the $[0,2\pi[$ range. Phase mapped so obtained needs to be unwrapped before being converted into shape information.

3. Surface reflectivity

The reflectivity of the surface can deteriorate the acquisition process. In particular, reflection, determines a return light directly into the optics of the camera, and carrying them in saturation and impairing the regularity of the pattern. This determines a deterioration due to the acquisition of a series of products artifacts that leads to the generation of very numerous noisy point clouds [10]. Deterioration can occur even with opaque areas causing measurement errors associated with the reduction of the contrast of the projection pattern, and in areas with high inhomogeneity, which compromises the pattern regularity. A possible solution involves the use of a thin layer of whitening product to make the whole surface homogeneous. However for applications on cultural heritage or, more generally, in contexts where it is not allowed to contaminate the surface, it is unthinkable to the application of a spray. In this paper, in addition to identifying an optimal frequency of the projection pattern it is proposed an innovative approach intended to homogenize the quantity of reflected radiation, implementing an *Adaptive Lighting Algorithm* that varies locally the lighting level to compensate for any lack of homogeneity, in terms of distribution reflectivity of the object under examination. It may, in fact, define a certain acceptance range of homogenization and perform an adaptive control at the local level of illumination so that the detected values fall within that interval. The correction is made on the projected light on the piece to be tested while the control is a function of inhomogeneities evaluated the recorded from the camera. However, one must remember that the reference systems of the room and projector are different. In this regard they exploit the affine transformations [11, 12], that is, any composition of a linear transformation with a translation, scaling and rotation.

4. Experimental procedure

In this section the steps to identify the optimum frequency of the pattern projection and the execution procedure of lighting adaptive algorithm are described. The measuring system provides a triangulation scheme as shown in Figure 1. The set-up of measure consists of a standard CCD camera with a resolution of 2452x2056 pixels, a frame rate of 9 fps, an ADC of 14 bit and an LCD projector with a resolution of 1024x768 pixels. The camera is equipped with an optics with a focal ratio of 2.8 and a focal length of 50,2mm. The object examined is a white marble block, smooth and with non-uniform reflectivity. The size of the object is 87x87x19mm. It is placed in such a way that the projector illuminates the full surface of the marble block while the camera presents its optical axis perpendicular to the work plane and simultaneously parallel to the block, all suitably bound on an optical table.

Fig.1 *Triangulation scheme of the measuring system*

The fixed geometric parameters are the origin of the camera, the distance between the camera and the projector, equal to 530mm, and the angle between the room and the distance projector and the distance between the camera and the marble block, equal to about 46 °. The software tool used to analyze the pattern is the Fringe Application while LabVIEW is used to realize the lighting adaptive algorithm.

The procedure of the identification of the optimum frequency involves the projection of a pattern fringes, that is, of vertical stripes with a sinusoidal distribution of gray levels. The projected pattern have the frequency equal to 0.2, 0.1 and 0.0125 px-1 respectively (Figure 2). The patterns will be processed, by processing the image of the projected pattern on the object, to obtain the map of unwrapped phase.

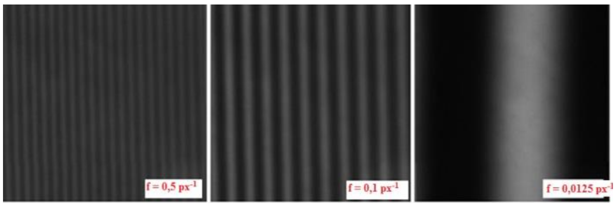

Fig.2 *The frequency variation of the projected pattern*

In the previous section, it was highlighted as highly reflective areas or dark areas can cause serious problems during the acquisition phase of the projected pattern, like a reduction the accuracy of measurement and the appeareance of measurement artifacts. In the following paper, it has been realized a suitable adaptive algorithm that would allow to detect the inhomogeneities of areas in terms of reflectivity, and would allow a correction based on local lighting variation. Figure 3 shows a flow chart of the steps of the algorithm. The algorithm consists of three phases. In the first phase, the algorithm calculates the coefficients of the affine transformations in the following way: a set of pixels, of known dimensions, is screened in the projector reference system and then the camera acquires this set, in its reference system. In this way, the coefficients of translation and of not uniform scaling are obtained. These coefficients are used to apply the affine transformations, so the algorithm captures the image from the camera and provides the coordinates in the projector reference system to the area to be corrected. It can be observed that the coefficients change in the control volume. The second phase is the monitoring. The camera control is performed by dividing the image in several subsets and for each of them by evaluating the maximum and minimum values. In the correction step, an average intensity of light in grayscale is projected on the object examined so the brightness recorded is compared with an average reference value, the intensity value for which you will have to increase or decrease the level of light intensity. In the last phase the correction is realized for each pixel whose intensity is above a certain range of homogeneity set, you will have to reduce the illuminance in corresponding pixels, transformed projection. Similarly, if the intensity detected is too low it will proceed to increase the illumination value in the corresponding pixel transformed projection. The correction achieves iteratively until the camera does not provide a value of the acceptable brightness. This value is included in a uniformity interval set according to the brightness of the environment of work.

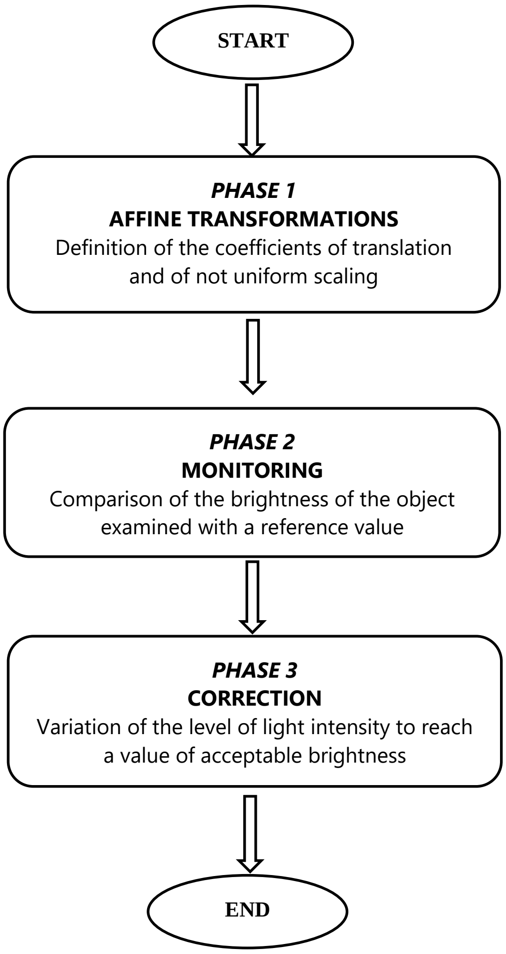

Fig.3 *Process of Adaptive Lighting Algorithm*

5. Results and discussion

In the analysis procedure of the fringes is noted, for a frequency of 0.0125 px^{-1}, an excessive problem associated with the operation of filtering, since the carrier frequency is too adjacent to the background noise in addition to excessive oscillations of the phase in the horizontal cross section (Figure 4, a). For a frequency of 0.2 px^{-1} it has highlighted an excessive reduction of the contrast resolution of the problems related with the mathematics of the problem and thus the need to adopt additional filters (Figure 4, b). For a frequency of 0.1 px^{-1} are visible small and negligible oscillation of the phase in the horizontal cross section (Figure 4 c). As regards the adaptive lighting algorithm, it was verified the ability to identify the areas that show anomalies, according to the set of control criteria, and the relative correction. The major difficulty is presented in the realization of the ROI filter to minimize the effects of adjacent subset to that of current control so that control of the camera is executed in the same correction area of the projector. A better accuracy of the filter is obtained by a projection system and to control grid, as shown in Figure 5.

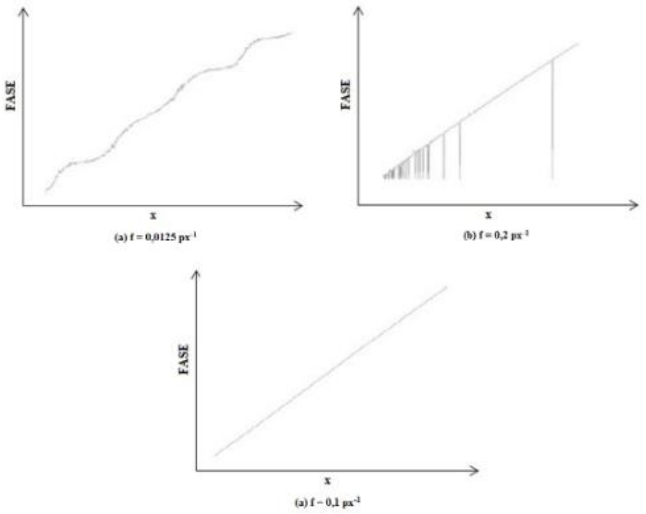

Fig.4 *Cross section of the horizontal phase to frequency: (a) 0,0125 px*$^{-1}$*, (b) 0,2 px*$^{-1}$*, (c) 0,1 px*$^{-1}$

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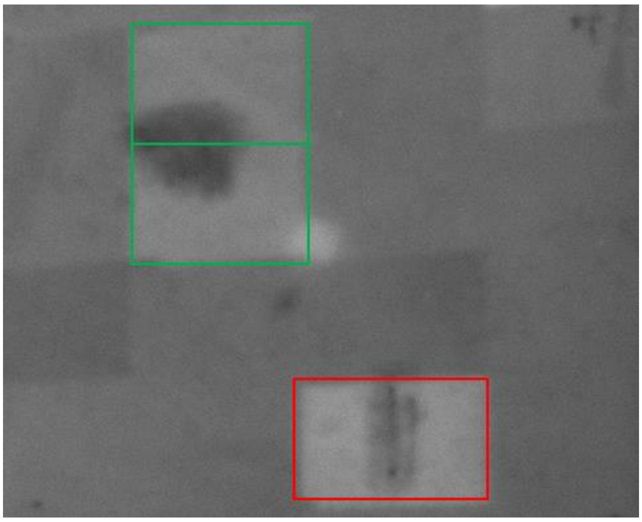

Fig.5 *Final result of Adaptive Lighting Algorithm*

In the red area (a) it is evident that the algorithm works effectively on the anomaly identified, properly increasing the brightness. In the green area (b) the correction is less effective, since the anomaly is present in the intersection between two control subset.

7. Conclusions and future works

It was identified a range of frequencies, such as to ensure a good precision. We note that, high frequency ensures better accuracy, against decreases in contrast, thus making difficult the measurement of high step like in complex shapes. Furthermore the mathematical ambiguity increases because the number of fringes is high. Instead, a low frequency reduces the number of the fringes and the measurement accuracy. Obviously, it is necessary to operate within this range to ensure efficient and correct measurement. As regards the problems related to the surface reflectivity, the realized algorithm acts in an effective manner when meets the inhomogeneities if the projection system and the control system are able to compensate the distortion of the projected grid, caused by the triangulation configuration. If this is not made it has a less effective correction, as the inhomogeneity may be present in the intersection between two scan cells. Reducing the grid size, increases the computational cost and the difficulty in compensating for the distortion of the projection grid. A good compromise provides for the correction of the same directly, during projection, namely compensating the distortion of the grid through the manipulation of the same in the opposite directions to those of the distortion. Future improvements to be taken could involve use of two projectors to minimize for distortion of the projection grid.

8. References

[1] R. Sitnik, “A Fully Automatic 3d Shape Measurement System With Data Export For Engineering And Multimedia Systems”, A Dissertation Submitted In Partial Fulfilment Of The Requirements For The Degree Of Doctor Of Philosophy In The Warsaw University Of Technology Warsaw, 2002.

[2] G.B. Broggiato, F. Campana, S. Gerbino, M. Martorelli, Confronto tra Diverse Tecniche di Digitalizzazione delle Forme per il Reverse Engineering, INGEGRAF, 2002, 1-11.

[3] D.Q. Huynh, R.A. Owens, P.E. Hartmann, Calibrating a Structured Light Stripe System: a Novel Approach, International Journal of Computer Vision, 1999, pp. 73-86.

[4] H. Miao, C. Quan, C.J. Tay, Y. Fu, X.P. Wu, Optical Edge Projection for Surface Contouring, Optics Communications, 2005, 16-23.

[5] G. Blahusch, W. Eckstein, C. Steger, Calibration of Curvature of Field for Depth from Focus, ISPRS Archives, 2003, 173-177.

[6] J. Salvi, J. Pagès, J. Batlle, Pattern Codification Strategies in Structured Light Systems, Pattern Recognition, 2004, 827-849.

[7] R. Talebi, A. Abdel-Dayem, J. Johnson, 3D Reconstruction of Objects using Digital Fringe Projection: Survey and Experimental Study, International Science Index, Mathematical and Computational Sciences, 2013, 1010-1019.

[8] S. Zhang, D. Van Der Welde, J.H. Oliver, Superfast Phase-Shifting Method for 3D Shape Measurement, Optics Express, 2010, 9684-9689.

[9] M.J. Tsai, C.C. Hung, Development of a High-Precision surface Metrology System using Structured Light Projection, Measurement, 2005, 236-247.

[10] A. Artusi, F. Banterle, D. Chetverikov, A Survey of Specularity Removal Methods, Computer Graphics Forum, 2011, 2208-2230.

[11] R. Scateni, P. Cignoni, C. Montani, R. Scopigno, Trasformazioni Geometriche, Fondamenti di Grafica Tridimensionale, Università Di Pisa, 2015.

[12] M. Lunelli, Deformazioni Prospettiche, Geometria, Dipartimento Di Matematica e Applicazioni Università Di Milano-Bicocca, 2003.