Non contact 3D measurement scheme for transparent objects using UV structured light

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Abstract—**This paper introduces a novel 3D measurement scheme based on UV laser triangulation to ascertain the shape of transparent objects. Transparent objects are extremely difficult to scan with traditional 3D scanners because of the refraction problem observed in the visible range. Therefore, the object surface needs to be preliminary powdered before being digitized with commercial scanners. Our approach consists of using non contact measurement scheme while dealing with the refraction problem in visible environment. The object shape is computed by classical triangulation method based on stereovision constraint. The proposed acquisition system is composed of two classical visible range cameras and a UV laser source. The exploitation of the UV laser for triangulation system characterizes the novelty of the proposed approach. The fluorescence generated by the UV radiation enables to acquire 3D data of transparent surface with a classical stereovision scheme.**

Keywords-3D reconstruction; transparent objects; fluorescence; UV laser

I. INTRODUCTION

Shape estimation of transparent objects by non contact measurement system was a complex challenge for researchers in the field of computer vision. Diverse approaches to model transparent objects have been proposed in literature [1].

Existing 3D reconstruction methods applied on opaque objects had been extended and adapted, to ascertain transparent objects shape. Schechner [2] and Ben-Ezra [3] modeled the object surface and depth by a parameterized function. Schechner et al. estimated the object surface by using shape from focus from a sequence of image focus whereas Ben-Ezra and Nayar computed the object shape by using structure from motion. Murase [4] proposed a method to estimate the shape of an undulating transparent object by extracting the optical flows related to the apparent motion of the object, for surface normal calculation. Hata et al. [5] implemented genetic algorithm combining with multi-stripe lighting to extract shape of transparent objects. However, all these methods did not provide the correct shape of transparent objects due to the modeling limits and the non robustness of the extraction process.

Some specific methods in computer graphics had also been carried out to characterize transparent objects. Matusik [6] developed environment matting for graphic applications that rendered transparent objects. By modeling the effects of reflection, refraction, translucency, gloss and interreflection with a mathematical framework from the composite image of scenes, the process should assure the separation of transmitted background scene and reflected foreground scene observed on a planar glass, denoted backdrop. In addition to the requirement for a higher number of images to capture an environment matte, the methods also failed when the two refracted and reflected scenes mapped on the same backdrop.

Most of the reliable approaches for specular objects reconstruction, called photometric methods, were based on light control and exploited physics properties of the environmental lights, especially reflected lights [7-10]. Using polarization analysis on the rays reflected by the object, these methods [7-8] have proved to be effective for transparent surface shape reconstruction. Although, suggested methods using polarimetric imaging provided partial reconstruction of the object shape and dealt with interreflection with complexity.

Recently, researches focusing on transparent objects shape estimation have exploited wavelength beyond

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visible range. Infrared range was explored to estimate the shape of transparent objects by triangulation system in [11-12]. Results were proven to be consistent but the overall system relying on IR camera was costly.
In this paper, a novel approach based on fluorescence generated by UV lighting in a classical stereovision scheme to ascertain transparent objects shape with satisfying accuracy, is presented. The proposed approach is described in section 2 with presentation of some results and discussions in section 3. The last section emphasizes the advantages of our approach with suggestion of topics for our future works and is ended by a short conclusion.

II. TRIANGULATION WITH UV LASER SOURCE

A classical triangulation system based on UV laser source to estimate transparent objects shape has been developed. A stereoscopic system constituted of two cameras functioning in the visible range associated with a 244nm UV laser source of 5mW and a rotating UV mirror to control the object scanning, has been thereafter described.

A. Fluorescence exploitation

The choice of the UV environment range for structured light is motivated by the specificity of the application materials: transparent glasses and plastics. Indeed, classical glasses have a strong absorption band in the UV range (Figure 1) and appear opaque within this range.

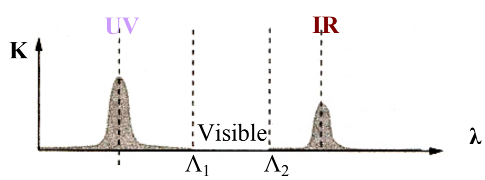

Figure 1. Absorption rate (*K*) of common glasses in function of electromagnetism wavelength.

Our system is based on the fluorescence generated by the absorption of the UV irradiation [13]. Object shape is revealed by the emission of bright spots wherever fluorescence takes place. These bright spots are then imaged by our calibrated [14] stereoscopic cameras and further analyzed with the epipolar constraint [15]. Neither the position of the laser source toward the stereoscopic system nor toward the object needs to be known. The laser source is manually controlled during the object scanning thanks to a rotating UV mirror. Images are acquired simultaneously in a dark environment with the calibrated stereoscopic cameras (Figure 2).

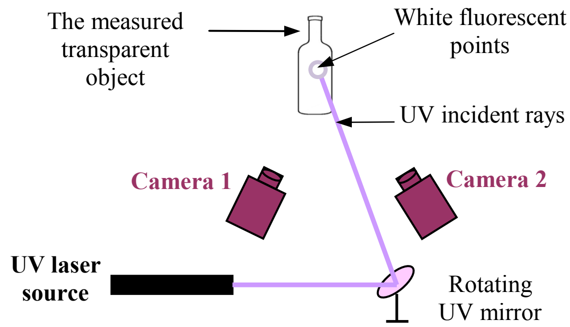

Figure 2. Fluorescence defining and capturing process.

B. Implementation

Let us briefly recall the main equation representing the image forming process. Considering $M=(X,Y,Z,1)^T$ as the 3D homogenous coordinate of an object point in world system and $m=(u,v,1)^T$ its corresponding 2D homogeneous image point coordinate in the image frame, with a scale factor $s \neq 0$, the equation is as follows:

$$sm = A[R \quad t]M \quad \text{where} \quad A=\begin{pmatrix} \alpha_u & 0 & u_0 \\ 0 & \alpha_v & v_0 \\ 0 & 0 & 1 \end{pmatrix} \qquad (1)$$

A is the matrix of intrinsic parameters with (α_u, α_v) as the focal length and $(u_0, v_0)^T$ the coordinate of the camera center in the image system. Specific for each camera, intrinsic parameters characterize the internal geometrical and optical parameters of the camera.

$$R=[r_1 \quad r_2 \quad r_3], r_i=(r_{1i} \quad r_{2i} \quad r_{3i})^T, \quad i=\{1,2,3\}$$
and $t=(t_1 \quad t_2 \quad t_3)^T$ *(2)*

R and t define the matrix of extrinsic parameters reduced to rotation and translation geometric transformations. Extrinsic parameters characterize the position and the orientation between the camera system and the world system.
The implemented reconstruction process can be summarized by the three main steps described below:

- Calibration step

We preliminarily calibrate separately each camera by using homography [14] from captured images of a planar square checkerboard in different orientations to determine intrinsic parameters, A in (1). Knowing orientations of the planar checkerboard issued of intrinsic parameters determination, the extrinsic parameters, R and t in (2), are calculated for each camera. The spatial relationship between both cameras,

$(R_{rl} \quad t_{rl})$ in (6), is thereby established from the extrinsic parameters.

- Matching step

From intrinsic and extrinsic parameters of each camera, the fundamental matrix is computed in order to establish the epipolar line equation on which matching step criterion will be based on. Indeed, for each given pair of images acquired by the stereoscopic system, we match the centroid of the fluorescent points in the left image with the closest fluorescent point of the right image to the epipolar line. Let E, be the space of the fluorescent points m'_i in the right image, $i=1,\ldots,n$ with n as the number of E elements, and Δ, the epipolar line whose equation is represented by $au'+bv'+c=0$, where a ,b ,c are the constants calculated with the image coordinates of a given point m in the left image. The corresponding point of m is the closest point m' among E elements whose distance to the epipolar line is the minimum. This minimization problem is represented by the expressions presented below:

$$m' = \min_{m_i \in \mathrm{E}} d(m'_i, \Delta) \quad (3), \qquad d(m_i', \Delta) = \frac{au'+bv'+c}{\sqrt{a^2+b^2}} \quad (4)$$

where d is the orthogonal distance between a point $m_i' = (u', v')^T$ and the epipolar line Δ.

- Reconstruction step

From each matched pair of points (m, m'), the 3D coordinates (M) of the object are estimated by least square methods knowing intrinsic and extrinsic parameters of each camera. The computation is done in the left camera system assuming the equations below:

For the left camera: $sm = A[I \quad 0]M \quad (5)$

For the right camera: $sm' = A'[R_{rl} \quad t_{rl}]M \quad (6)$

Where I is 3 by 3 identity matrix, A' is the matrix of intrinsic parameters related to the right camera and $(R_{rl} \quad t_{rl})$ is the spatial relationship between the calibrated stereoscopic cameras.

III. RESULTS AND DISCUSSIONS

With the triangulation measurement scheme described in the previous section, some transparent objects (Figure 3) are reconstructed: a white glass (Object1), a green bottle of wine (Object 2) and other glass or plastic objects.

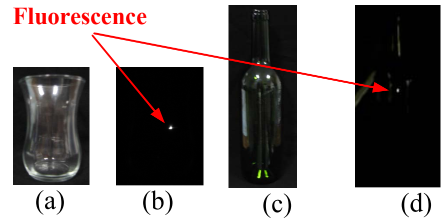

Figure 3. (a) White glass; (c) Green bottle of wine. (b) (d) Fluorescence observed on (a) and (c).

Our results are compared with "ground truth data" obtained from commercial scanner (with 0.1mm of accuracy) which requires the coating (with 0.015mm of thickness) of the sample prior to their digitization.

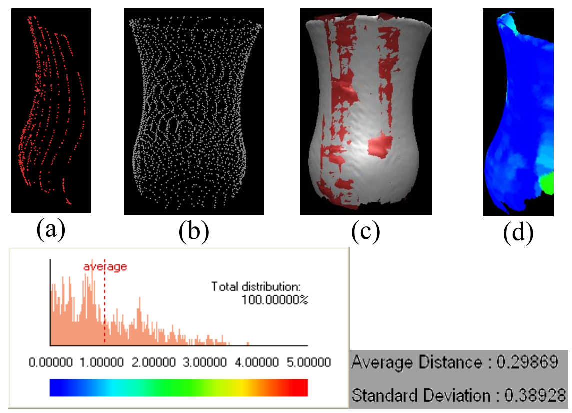

Figure 4. 3D points of the white glass: (a) obtained by our proposal; (b) obtained by an existing 3D scanner. (c) Superimposing of the models (a) and (b). (d) Deviation map related to the models in (c).

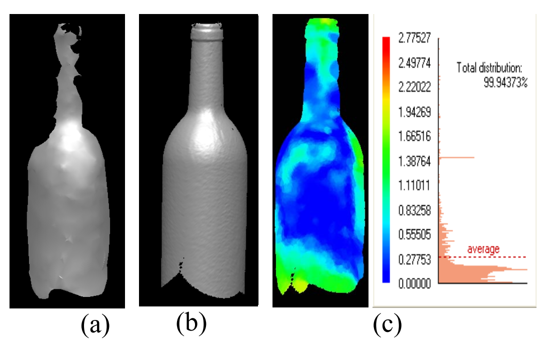

Figure 5. 3D textured model of the green bottle: (a) obtained by our proposal; (b) obtained by an existing 3D canner.(c) Deviation map related to the superimposing (a) and (b).

According to the deviation map related to the superimposed two models (Figure 4(d) and Figure

5(c)), errors are quantified by statistic parameters expressed in mm: μ as the average distance and σ as the standard deviation distance. By Size we refer to the object's height in mm. The variables N and M are respectively the number of points and the number of mesh triangles used to constitute 3D models.

We notice that the error is higher for the green transparent bottle. The error amount and the error difference between these two application objects are explained by the fact that the number of points N structuring 3D models is not sufficient and not regularly located. This is due to the manual moving of the UV laser source. Despite of these sources of inaccuracy, the obtained preliminary results are very satisfying and promising (Figure 4, Figure 5 and Table 1) with a standard deviation of 0.389 mm for the white small glass of 90mm height and a standard deviation of 0.813mm for the green bottle of 220mm height.

	Size	N	M	μ	σ
Object 1	90	1019	1682	0.298	0.389
Object 2	220	1227	2225	1.073	0.813

Table1. Results synthesis.

IV. CONCLUSION

We proved the feasibility of transparent objects shape estimation by the proposed measurement scheme using UV source. Our proposal enables to determine the transparent objects shape via non contact measurement with effectiveness. Our method is optimal compared with the conventional measurement techniques which operate in three steps for each inspected transparent object surface: powder coating, measurement and cleaning. Thanks to the portability of the system and its provided accuracy, the approach is perfectly adaptable for industrial applications such as glasses inspection in quality control and 3D modeling of transparent objects used in some other fields. All objects, reacting by fluorescence with an adequate UV laser source, are measurable with the proposed scheme. The UV laser source is chosen according to the nature of the application and the performance of the system is dependant on the internal properties of the considered materials. With our manipulated UV laser source, almost all transparent objects, glasses and plastics, are measurable irrespective of their color and their shape complexity. However the exploitation of the fluorescence mainly depends on the material refraction property (and consequently its thickness). We propose a deep analysis of the system limits for perspectives by analyzing the material and the UV laser properties and suggest enhancing our approach by optimizing the acquisition system with implementation of some pre and post treatment algorithms for data analysis before and after the reconstruction process.

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