Photogrammetry-based 3D digitization Method for Oil Paintings

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Abstract

This paper proposes a new oil painting digitization method using photogrammetry technology to compensate for the deficiencies of the existing methods. The color and the 3D geometric information of the oil painting are recovered better by acquiring several sets of orthophotomaps, and modeling accuracy is ensured with a control mesh or by flattening. The 3D reconstruction and digital representation of oil paintings mainly includes two aspects: 3D geometric information recovery of oil painting surface and color rendition of oil painting. Photogrammetry can acquire a digital 3D model of the surface geometrics of an oil painting, restore the color image and plane geometry of the painting in the form of orthophotomap, and implement the 3D digital representation of color in the painting.

Keywords : *3D digitization method for oil paintings, photogrammetry, 3D modelling*

1. Introduction

Oil paintings are reproduced primarily for decoration, promotion, dissemination, and reference. Reproductions have high value and great market demand, especially because the originals are difficult for ordinary consumers and art learners to obtain. High-fidelity reproductions are becoming increasingly popular. Currently, high-fidelity reproduction of oil paintings is achieved mainly through two methods, namely, manual copying and printing. Manual copying with oil paints often produces real and stereoscopic perception and feel. However, this process is time consuming, and the painting quality largely depends on the artist's painting skill. The following three printing methods exist:

1) Offset printing and digital inkjet printing (Wenhua Lian, 2007)1;

2) Screen printing (Anning Liu, 2002)2 ; and

3) Printing and paint thickness compensation (patent no. CN 103103814 A, 2013)3.

Offset printing and digital printing achieve high-fidelity replication of oil paintings visually, yet they are unable to replicate the feel of paintings. Screen printing cannot produce reproductions that are consistent with the originals given the unevenness and height of the paint. Moreover, paint thickness compensation in screen printing cannot achieve consistency with the originals in terms of stroke thickness, and its procedures are complicated.

Color representation and consistent stroke thickness with the originals are the main issues to be solved to obtain high-fidelity replications of oil paintings. Such issues can be addressed by 3D printing, in which a digital model file is used as a basis to print layer by layer with powdered metal, plastic, or any other adhesive material4.

In conclusion, 3D digitalization technology is very important for 3D printing and high-fidelity reproductions of oil paintings.

2. Photogrammetry-based 3D reconstruction of oil paintings

The 3D reconstruction and digital representation of oil paintings mainly includes two aspects: 3D geometric information recovery of oil painting surface and color rendition of oil painting. Photogrammetry can acquire a digital 3D model of the surface geometrics of an oil painting, restore the color image and plane geometry of the painting in the form of orthophotomap, and implement the 3D digital representation of color in the painting.

2.1 Control grid and image capture

An original painting is shown in Fig. 2-1 and has stereoscopic undulating strokes for the petals.

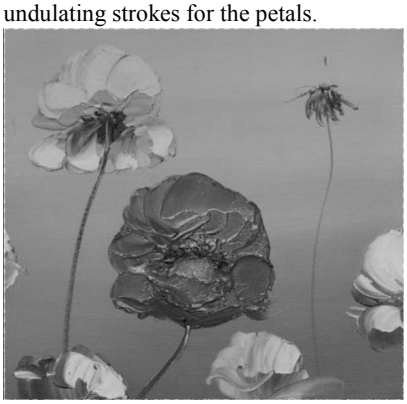

Fig.2-1 *Original painting.*

A control grid is mainly designed to suppress measurement errors. A control grid plate used as the control plane to restore the painting, the interval of the control grid is 40 mm, and the grid contains 10 mm×10 mm square black boxes with a measurement accuracy of up to 0.1 mm. A standard light box with D65 illuminants is used to control the effect of ambient light. The oil painting is affixed flush to the control panel, as shown in Fig. 2-2.

Fig. 2-2 *Control panel and measurement grid.*

After the control grid is established, a Canon 5D II camera with a fixed focus lens is used to obtain a total of 35 sequence images. The focal length is set to 50 mm, and the shooting distance is 50 mm, as shown in Fig. 2-3.

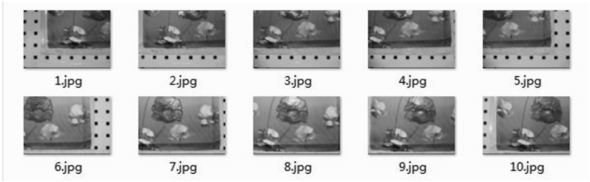

Fig. 2-3 *Image sequence.*

2.2 Analysis of photogrammetry triangulation

Collinearity equation is a condition equation that represents the image point, the center of projection, and the object point that should be located on a same straight line (Fig. 2-4).

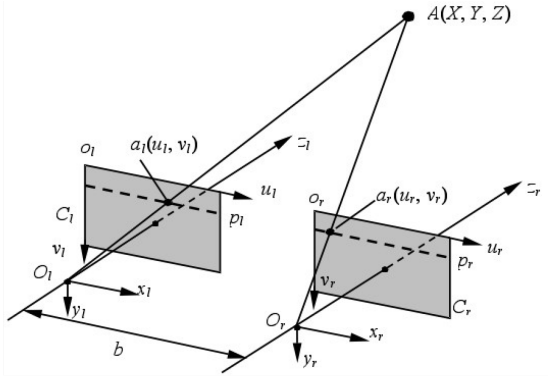

Fig. 2-4 *Schematic of collinearity equations .*

The coordinates of the object point can be used to solve when the known stereoscopic image corresponds to the orientation elements of two photos5. Collinearity equations (Formula 2-1) are the most important analytic relations for photogrammetry, and two of them are plane equations. The intersecting line of the two corresponding planes is also the line where the image point, the center of projection, and the object point are located.

$$x - x_0 + \Delta x = -f\frac{a_1(X-X_s)+b_1(Y-Y_s)+c_1(Z-Z_s)}{a_3(X-X_s)+b_3(Y-Y_s)+c_3(Z-Z_s)}$$
$$y - y_0 + \Delta y = -f\frac{a_2(X-X_s)+b_2(Y-Y_s)+c_2(Z-Z_s)}{a_3(X-X_s)+b_3(Y-Y_s)+c_3(Z-Z_s)} \quad (2\text{-}1)$$

where x, y respectively represent the image plane coordinates of the image point;

x_0 , y_0 , f represent the interior orientation elements of the image;

Δx , Δy represent the correction values of system errors that are introduced by the coordinates of the image point;

X_s , Y_s , Z_s represent the object space coordinates of the position of the principal point of the camera when shooting;

X , Y , Z represent the object space coordinates of the object point;

a_i , b_i , c_i (i=1, 2, 3) represent the cosines of 3 exterior orientation elements of the image in 9 directions;

The interior orientation elements are obtained through camera calibration, as given in the following formula.

Radial distortion:

$$\begin{cases} x_u = x_d\left(1+k_1r^2\right) \\ y_u = y_d\left(1+k_2r^2\right) \end{cases} \quad (2\text{-}2)$$

k1, k2 represent the radial distortion parameters;

$r = \sqrt{x^2+y^2}$ represent the polar radius of point to the center of the imaging plane;

xu ,yu represent the coordinates of xd,yd after calibration.

Decentering distortion:

$$\begin{cases} \delta_{xd} = p_1\left(3x_d^2+y_d^2\right)+2p_2x_dy_d \\ \delta_{yd} = p_2\left(x_d^2+3y_d^2\right)+2p_1x_dy_d \end{cases} \quad (2\text{-}3)$$

xd , yd represent the coordinates of actual point;

p1, p2 represent the decentering distortion parameters.

The results seen as follow:

Table 2-1 Camera calibration data (unit: mm)

interior orientation elements			Distortion correction parameter			
Focal-Len	x_0	y_0	k_1	k_2	p_1	p_2
53.0279 1	0.00817 7	0.04196 4	2.402 e-000	5.553 e-017	6.068 e-008	4.729 e-007

With the use of the control information available on the carrier platform and the acquired image for photogrammetry aerial triangulation by LENSPHOTO system automaticlly, six exterior orientation elements of each image are obtained, as shown in the following table:

Table 2-2 Exterior orientation elements of the image

linear elements(unite: mm)			
ID	*Xs*	*Ys*	*Zs*
1001	71.692	3.716	416.783
1002	160.047	1.588	422.092
1003	221.435	1.557	423.021
1004	271.147	1.802	421.971
1005	339.917	1.549	417.466
1006	342.58	74.244	423.867
1007	277.719	75.554	428.494
1008	230.162	78.806	430.056
1009	171.194	76.439	429.5
1010	117.627	74.744	426.997
1011	65.593	76.186	422.838
1012	67.21	140.938	425.739
1013	129.999	138.58	430.829
1014	191.824	138.494	433.014
1015	249.514	139.733	432.674
1016	307.413	141.132	429.953
1017	357.936	141.452	425.576
1018	360.538	216.69	425.971
1019	310.385	221.351	430.215
1020	259.549	226.207	432.867
1021	207.521	227.01	433.643
1022	152.331	227.888	432.441
1023	99.983	228.584	429.172
1024	101.292	291.811	427.171
1025	97.981	293.917	426.829
1026	162.401	295.512	430.246
1027	226.246	296.514	430.739
1028	289.258	297.375	428.67
1029	343.392	298.821	424.443
1030	343.504	356.699	419.706
1031	272.988	353.335	424.943
1032	213.031	350.936	426.391
1033	155.814	344.691	426.086
1034	96.85	342.544	423.059
1035	51.148	345.778	418.649

angle elements(unit: degree)			
ID	Phi	Omega	Kappa
1001	8.59485	-3.6647	0.03352
1002	8.68347	-0.60852	-0.12699
1003	8.68914	1.52513	-0.06077
1004	8.66924	3.25374	-0.06677
1005	8.7875	5.74649	-0.03428
1006	6.07698	5.82928	0.49472
1007	6.04084	3.52869	0.70219
1008	5.96971	1.85127	1.27968
1009	6.10153	-0.21567	0.97029
1010	6.19715	-2.12463	0.69722
1011	6.1662	-3.94012	0.88023
1012	3.60562	-3.77204	1.44554
1013	3.9492	-1.68787	1.82183
1014	3.97075	0.54517	1.95839
1015	3.87468	2.60152	2.23126
1016	3.80482	4.67805	2.60951
1017	3.71014	6.30855	2.45238
1018	1.5045	6.54967	3.14439
1019	1.1811	4.80208	3.65246
1020	0.97896	3.03272	4.3175
1021	0.96299	1.20345	4.45399
1022	0.98881	-0.75609	4.67229
1023	1.10281	-2.56142	5.0965
1024	-1.04216	-2.57623	3.68176
1025	-1.11481	-2.64462	4.64974
1026	-1.26319	-0.34378	4.90574
1027	-1.32963	1.91508	5.28439
1028	-1.34756	4.17922	5.87893
1029	-1.27552	6.07808	5.42075
1030	-3.29022	6.07678	5.34287
1031	-3.2885	3.54492	4.34187
1032	-3.1807	1.45214	3.79551
1033	-2.94153	-0.64639	2.0446
1034	-2.79908	-2.77061	1.75932
1035	-2.86843	-4.31815	2.72225

Reconstructive accuracy analysis is created by LENSPHOTO system automatically, the root mean square of observation value and re-projection is 0.001330, the vertical accuracy of control points are shown in the following table:

Table 2-3 Vertical accuracy of control points

No.	ΔX(mm)	ΔY(mm)	ΔZ(mm)
1	0.0031	0.0041	0.0036
2	0.0025	0.0032	0.0053
3	0.0021	0.0036	0.0027
4	0.0037	0.0032	0.0018
5	-0.0028	-0.0026	-0.0063
6	-0.0057	-0.0013	-0.0076

The 3D reconstruction results of the oil painting surface based on the interior and exterior orientation elements are shown in Fig. 2-5, 2-6.

Fig. 2-5 3D reconstruction results of the oil painting.

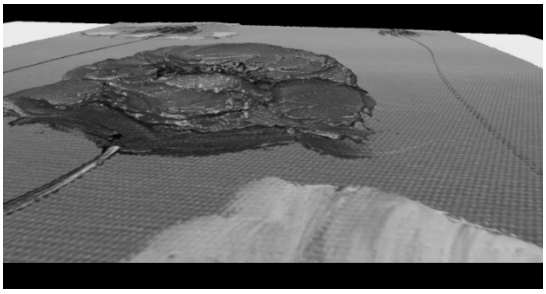

Fig. 2-6 Detail of 3D reconstruction

3. Conclusions

In this paper, a 3D digitization method for oil paintings is demonstrated experimentally. Digital photogrammetry is used for 3D modeling of oil paintings. Modeling results show that digital photogrammetry can effectively establish a colorful 3D model for oil paintings. The principle of the 3D model for oil painting surfaces is identical to that of DEM. This 3D digitization method for oil paintings compensates for the deficiencies of existing 2D digitization and reproduction methods and expands the applications of 3D printing. However, modeling accuracy and color rendition require further research.

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