РЕКОНСТРУКЦИЯ ПОВРЕЖДЁННЫХ ФРЕСОК С ИСПОЛЬЗОВАНИЕМ МЕТОДА КЛЮЧЕВЫХ ТОЧЕК

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Аннотация: Со временем фрески – живописи по сырой штукатурке, в результате природных воздействий (землетрясений, ураганов, наводнений) и человеческого фактора (вандализм, террор и войны) повреждается или подвергаются фрагментированию. Реконструкция поврежденных и фрагментированных фресок похожа на решение большой головоломки. Очень важно, была ли известна какая-либо информация о фреске, до процесса сборки фрагментов деталей этой головоломки. Стратегия решения задачи определяется в зависимости от имеющихся знаний. В данном исследовании в качестве предварительного знания используются эталонные изображения фресок до фрагментации. В качестве стратегии решения фрагменты собраны с соответствующими исходными образами. Для обеспечения эффективности процесса сопоставления предложены методы на основе ключевых точек. С течением времени происходит истирание, появляются трещины, меркнут цвета и стираются рисунки на поверхности фресок. Этот факт является важным фактором для принятия решения о том, какие методы, основанные на ключевых точках, будут использоваться в процессе восстановления.

В этом исследовании изучались различные исторические артефакты, для реконструкции фресок были использованы методы ключевых точек Харриса и МИПП (*Масштабно-инвариантное преобразование признаков*), и полученные результаты сопоставлены. Трещины, ссадины и обесцвечивание фресок приводят к обнаружению большего количества угловых точек в методе Харриса.

Установлено, что метод Харриса имеет больше преимуществ в реконструкции. Кроме того, экспериментальным путём установлено, что метод Харриса дает такие же результаты и за меньшее время завершает реконструкцию, чем ключевой метод МИПП.

Ключевые слова: искусственный интеллект, пазлы, масштабно-инвариантное преобразование признаков, детектор Харриса, реконструкция разбитых фресок.

RECONSTRUCTION OF FRAGMENTED FRESCOES USING KEYPOINT BASED METHODS

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Abstract: Fresco paintings have been fragmented and damaged due to natural affects (earthquakes, storms, flood) and human factor (vandalism, terror and wars). Reconstruction of damaged and fragmented frescos is similar to solution of a big puzzle. It is very important, if any prior knowledge is acquired or not, before the process of fragment assembly of puzzle parts. The solution strategy of problem is determined according to the obtainable prior knowledge. At this study, reference images of frescos before fragmentation are used as a prior knowledge. As a solution strategy, fragments are assembled with matching original reference images. Using keypoint based methods are suggested in order to make matching process effective. Abrasion, cracks, deterioration of colours and figures used on the surface of frescos occur over time. This fact is important factor to decide which keypoint based methods will be used in matching process. In this study, different historical artefacts examined, reconstruction of frescos are implemented by using the SIFT (*Scale-invariant feature transform*) and the HARRIS methods and the success of these methods are compared. Cracks, abrasions and discoloration led to detection of more corner points in the HARRIS method. It was found that the HARRIS method has more advantage in the reconstruction. Moreover, in the experimental results it was shown that the HARRIS based method produced results as successful as SIFT and completed reconstruction within less time.

Key words: artificial intelligence, jiggsaw puzzle, HARRIS detector, SIFT, frescoes reconstruction.

I. Introduction

Historical artifacts broken and fragmented due to natural disasters such as earthquakes and hurricanes and human factor (vandalism, terror and wars) [1]. The reconstruction of these fragments is similar to the solution of a big puzzle. Therefore, manual reconstruction process takes great effort and a long time [2].

In our age, considering computer technology such as artificial intelligence, fragmented artifacts can be reconstructed with less effort and less errors using computer software. Looking at the studies in the literature,

Papaodysseus et al. [3] proposed a new method to repair frescoes unearthed during archaeological excavations. This method puts together fragment pairs that fit the best, in terms of their shapes. Sağıroğlu et al. [4] utilized the color and texture information at the edges to reconstruct fragmented archaeological artifacts such as ceramic tiles. The inpainting [5] method was used to get the color and texture information from the edges. Then, fragment pairs with the most similar features were put together and thus the reconstruction was made. Massimo and Toniolo [6] reconstructed frescoes with a method based on recognizing patterns rotation invariant. Researchers managed to obtain pre-fracturing photographs of the frescoes. Fresco fragments were put together by matching with reference images. One of the disadvantages of this study is that reconstruction time and success rates could not be reported.

The literature generally studies on the reconstruction artifacts of unknown original (obtained at archaeological excavations). But reconstruction of artifacts using reference image was found only one study. The study proposed by Massimo and Toniolo [6] in 2005. Considering the recent increase in acts of terror and ongoing warfare, the need for methods to reconstruct artifacts of known original is increasing. The proposed study aims to contribute to filling this gap in the literature.

This paper is organized as follows. Section 2 describes the details of the method. Section 3 presents our experimental results of the proposed method. The evaluation is given in Section 4.

II. Proposed Method

Fragmented frescoes are reconstructed using SIFT and HARRIS based methods. The outline of the proposed method can be found at Figure 2.

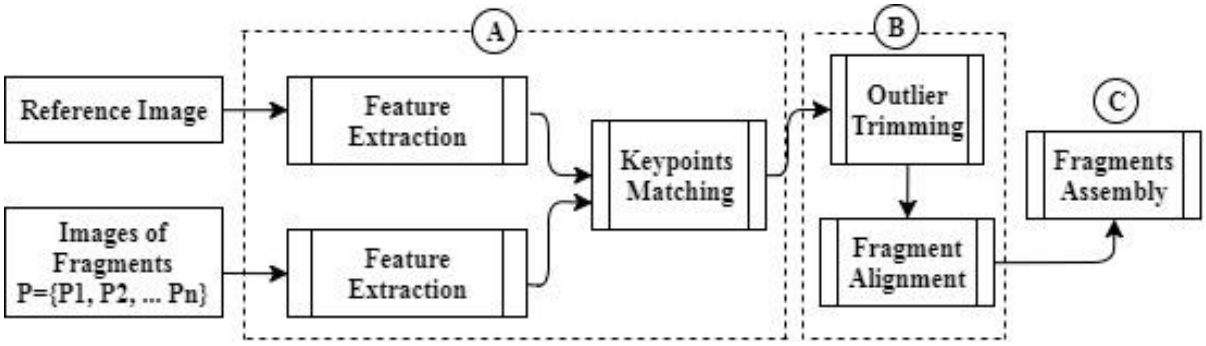

Figure 2. A flow diagram of fresco reconstruction as proposed in this study.

A. Matching of the fragment with reference image

At this stage, feature extraction is performed from fresco fragments and reference images. Afterwards, the keypoints are matched with one another. SIFT [7] and Harris Corner Detection [8] methods were used for the matching.

SIFT (Scale-Invariant Feature Transform) Method:

The SIFT method is composed of 4 main stages. *(1) Scale space extreme detection:* The Gaussian filter is used to create the scale space. The Gaussian filter enables image convulsion. The difference with these images gives the differences of Gaussians (DoG). The extremum points of the difference of Gaussians show the potential keypoints in the image. (*2) Keypoint localization:* The DoG operator is influenced by intense edges and is sensitive to noises in the image. Therefore, potential keypoints found to be erroneous are eliminated using 2nd degree Taylor polynomial expansion and Hessian matrices. *(3) Orientation assignment:* Keypoints are assigned an orientation to detach these points from the rotation. To do this, gradient sizes and orientations around each keypoint are calculated. The most distinct orientation in the area is assigned as the orientation of the feature point. *(4) Keypoint descriptor:* 16x16 blocks are created around the keypoints. These are divided into 4x4 blocks. Histograms, gradient tendencies of which contain 8 bins are created within each block. Feature vectors with 4x4x8=128 elements in total are obtained for each keypoint [7].

HARRIS Corner Detector:

With this method, changes in intensity are seen by slightly moving a small, designed frame around the point in any direction. The changes in intensity values indicate whether the point is a corner point or not. The intensity change of points should be calculated as shown in equation (1).

$$E(u,v) = \sum_{x,y} w(x,y)[I(x+u, y+v) - I(x,y)\,]^2 \quad (1)$$

In equation (1), w (x, y) refers to the window function (Gaussian window), I(x+u, y+v) refers to shifted intensity and I(x, y) refers to the intensity value of each pixel. Corner detection is reformulated through approximation as shown in equation (2).

$$E(u,v) \cong [u,v]\, M \begin{bmatrix} u \\ v \end{bmatrix} \quad (2)$$

The formula for matrix M is as shown in equation (3).

$$M = \sum_{x,y} w(x,y) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \quad (3)$$

In this method, the latent values of matrix M have the proposed corner reaction value. The formula is as in equation (4).

$$R = \det(M) - k\,(traceM)^2 \quad (4)$$

In equation (4), R refers to the corner response value and it has the equations $\det(M) = \lambda_1\lambda_2$ and $traceM = \lambda_1 + \lambda_2$. The value of constant k is suggested to be chosen between 0.04 and 0.06. If R has a positive and great value, the pixel is a corner point. If R has a negative and great value, the pixel is then an edge point. If R has a low value, the pixel is neither at an edge nor at a corner [8].

B. Determining position of fragments on the frescoes

There need to be outliers in the matching to detect a fragment's position on the fresco. In this study, erroneous points were eliminated with the RANSAC [9] method. For instance, in Figure 3 a fresco fragment was matched with the reference image using the HARRIS method and mismatched keypoints were detected with the RANSAC method.

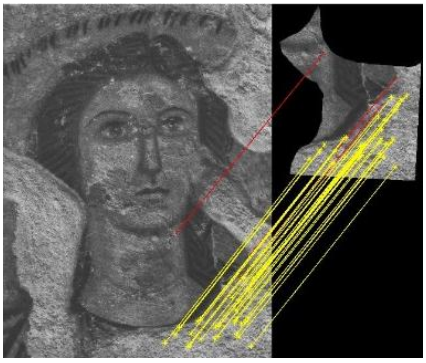

Figure 3. Correctly-matched keypoints are colored yellow while mismatched points, which are detected with the RANSAC method, are colored red.

Pieces need to be aligned in order to be but on the frame the right way. In this study, fragments' rotation angle assumption is calculated with the RANSAC method, over correctly matched keypoints. Fragments are aligned by being rotated as per their rotation angle.

C. Fragments Assembly

Correctly aligned fragments are assembled by being placed in a hollow frame mold that is the exact size of the reference image. After all fragments are put in the frame, the success rate of the reconstruction needs to be determined. In this study, the success rates of the reconstructed frescoes are calculated with the method developed in [10].

III. Experimental results

Abrasions, cracks, color and figure deteriorations occur over time on the surfaces of frescoes. This study examines whether the success of keypoint based methods to be used are affected by this destruction or not. SIFT and Harris Corner Detection methods were applied to a fresco and the detected keypoints are shown on Figure 4.

(a) **(b)** **(c)**

Figure 4. (a) Image of the fresco and details of the destruction on the surface **(b)** The number of keypoints detected with the SIFT method: 1.423 **(c)** The number of keypoints detected with the Harris method: 5.239.

In Figure 4, the destruction on the fresco affected the SIFT method negatively, but affected the Harris Corner Detection method positively and enabled discovering many more keypoints.

Frescoes in Figure 3 and Figure 4 were fragmented in computer environment and then reconstructed with SIFT and HARRIS based methods. The obtained results are shown on Figure 5.

(a) **(b)** **(c)** **(d)**

Figure 5. (a) and **(c)** show the frescoes being reconstructed with SIFT based methods, while **(b)** and **(d)** show them being reconstructed with Harris based methods.

In Figure 5, it is seen that fragmented frescoes are similarly successfully reconstructed with both methods.

Reconstruction of frescoes times and success rates are given in Table 1.

Methods	**Harris Corner Detection**			**SIFT**		
#	**Number of Keypoints**	**Time (seconds)**	**Success Rate (%)**	**Number of Keypoints**	**Time (seconds)**	**Success Rate (%)**
Figure 3	2,167	8.71	96.4734	1,390	14.09	95.7229
Figure 4	5,239	24.25	97.2518	1,423	30.54	97.5361

Table 1. Reconstruction times and success rates of Harris and SIFT based methods

Table 1 indicated that both methods have high and close success percentages. Though the Harris based method detected more keypoints, the reconstruction time was found to be less.

IV. Conclusion

In this study, fragmented frescoes were reconstructed with SIFT and HARRIS-based methods. The destruction on the surface of the frescoes enabled the Harris Corner Detection method to detect more keypoints. Furthermore, the HARRIS-based method's reconstruction time was calculated to be less. The success percentages of the two methods were high and close to each other. Therefore, using HARRIS-based methods in the reconstruction of fragmented frescoes will be more advantageous. Moreover, using reference images in the restoration of fragmented frescoes will reduce the errors.

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