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Feature identification in archaeological fragments using families of algebraic curves

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Abstract

A method is proposed to identify and localize semantic features like anatomical characteristics or decorations on digital artefacts or fragments, even if the features are partially damaged or incomplete. This technique is based on a novel generalization of the Hough transform. Its major advantages are the relative robustness to noise and the recognition power also in the case of partial features. Our experiments on digital models of real artefacts show the potential of the method, which can work on both 3D meshes and point clouds.

Categories and Subject Descriptors (according to ACM CCS): Computing methodologies - Computer graphics - Shape modeling - Shape analysis.

1. Introduction

In the Cultural Heritage domain (CH), applications of 3D modelling are mainly focused on objects' geometry and appearance acquisition, reconstruction and visualization. These processes are now widely used, and archaeologists ask for 3D models, which become a valuable source to support activities of comparative analysis [PPY*16]. Some of them are related to *re-unification* tasks, e.g. to select fragments belonging to the same archaeological type or to find matching between fragments for reassembly purposes. Other activities are related to *re-association* purposes, to classify objects according to various criteria, e.g., geometric shapes, textures or semantic features.

Several problems make these tasks not easy. Archaeological artefacts are often broken, eroded, worn, or incomplete and their quantity is extremely vast, distributed and fragmented. Therefore global similarity is often not applicable in the CH domain. When dealing with broken fragments, a further challenge is to identify, and locate, partial features in portions of models (for instance, a broken eye in a part of a head), taking advantage of the whole knowledge associated to them. Therefore, methods must deal with multimodal information in combination (e.g., geometry, pattern, texture, colour, reflectance). Another consideration is that the description of an artefact is usually a text often integrated with pictures or manual sketches, but completely unrelated to its digital model. Therefore its semantic features are recognizable or localizable in the 3D model only through visualization, while they should be attributed to it. As we know from the textual description which semantic features are present in the artefacts, we use this information as input for the identification of these features in the 3D models.

In the case of human-made objects, feature curves have been shown to be quite a flexible choice for representing the salient parts of models [HT11]. Feature lines are often characterized as ridges and valleys, thus representing the extrema of principal curvatures [YBYS08]. Zero-mean curvature curves and zeros of the Gaussian curvature are other ways to define feature lines because they respectively divide concave and convex parts or hyperbolic and elliptic regions [Koe84]. Finally, demarcating curves are the zero-crossings of the curvature in the curvature gradient direction [KST08]. Once the feature points have been detected, a popular choice is to fit them with a quadratic spline approximation, as done in [APM15] to drive fragment reassembly. However, the set of curves candidates to fit a feature line is very large: recently 3D Euler spiral has been proposed as a natural description for line drawings and silhouettes [HT11].

Our method recognizes various features, possibly compound, and selects the most suitable profile among a family of algebraic curves. To do this, we use an extension of the Hough transform technique to extract and approximate the feature curves from a set of potentially significant points. Since its original conception, the Hough transform has been extensively used and many generalizations have been proposed for identifying occurences of arbitrary shapes, most commonly circles or ellipses [Bal81]. More recently, the Hough transform technique has been extended and applied to different families of algebraic curves (see [BR12] and [BMP13]). This is undoubtedly an advantage of the method, which allows to deal with various shapes, possibly compound, and to choose the most suitable approximating profile among a broad vocabulary of curves.

Using a method based on the Hough transform offers also other

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benefits, like a relative robustness to noise and a good recognition power also in the case of partial features. Our experiments on digital artefacts show the potential of the method, which can work on both 3D meshes and point clouds.

2. Description of the method

The method we propose is suitable for extracting peculiar curves from feature points of a given 3D model. To show its characteristics we have applied it to the analysis of statue's fragments, focusing on some anatomical features (such as eyes and mouth), usually highlighted by the curator in the free form text notes. Anyway, the method is general and could be applied to other cases (other anatomical features, extraction of patterns, localization of decorations).

We assume that the geometric model of the object is available as a triangulated mesh with colour, since, nowadays, many sensors are able to acquire not only the geometry of an object but also its colours. Nevertheless, these working assumptions are not fully needed by our methodology and can be weakened. The model's photometric features, which, if present, contain rich information about the real appearance of objects (see [TWW01]), can be exploited alone or in combination with the shape properties for extracting the feature points set. However, if the model has no colour, only the geometrical information will be used. Further, our methodology does not require any regularity of the triangulated mesh. Good properties (like watertightness) are needed requirements of the used software, though in principle our approach is able to handle even simple point clouds. To this end, in our experiments (see Section 3), when dealing with non optimal meshes or point clouds, a preprocessing step will be adopted.

The methodology, also described through an illustrative example (a scanned artefact of the STARC repository [STA], see Figure 1 (a)), consists of 4 stages that permit us to apply the Hough transform to points instead of images. In the first step, the feature points are characterized by means of geometric and/or photometric descriptors. The geometric properties can be easily derived using classical curvature functions, like minimum, maximum or mean curvatures. Curvature quantities are computed and displayed using the Matlab Toolbox Graph [Pey]. A representation of the maximum curvature function computed on the model $\mathcal{M}$ is shown in Figure 1 (b). The photometric properties can be represented in different colour spaces, such as RGB, HSV, and CIELab spaces. The feature points $\mathbb{X}$ of the model $\mathcal{M}$ are extracted by selecting the regions at which these functions assume particular values (e.g high maximal curvature and/or low minimal curvature and/or low luminosity). In the second step, the selected vertices are divided into smaller connected components using the DBSCAN (Density-Based Spatial Clustering of Applications with Noise) method [EKSX96] (see Figure 1 (c)). The next two steps apply to each computed component. In the third stage, each subset is projected onto its best fit plane, a not restrictive operation of our method, since the features contour lines which we are interested to extract (like eyes and mouth) locally present a well identifiable shape mostly defined by planar curves. In the fourth step, each 2-dimensional set of feature points is automatically approximated by a feature curve through a generalization of the Hough transform technique (see [BMP13], [MPCB15], [TB14]). With respect to the previous literature, the application of the Hough transform to the projected 3D points is novel and do not undergo to grid approximation of the coordinates of the points. One advantage of this method is a larger family of algebraic curves used to approximate the desired features, thus being adaptive to approximate various shapes. In our "vocabulary" the set of primitives includes many algebraic curves in addition to the more common ones, like straight lines, circles, ellipses, parabolic lines, etc. These curves can be exploited to detect for instance eyes contours, pupils shapes and lips lines. Their equation are quadratic (ellipses and circles) and linear (straight lines) and depend on 3 parameters at most. In the case of an eye feature, one interesting family of algebraic curves is the so-called *geometric petal* [Shi95] whose shape resembles, for particular values of the parameters, the eye contour line. Applying our HT-based procedure to the family of geometric petal curves (see Figure 1 (c)), we get a particular instance of the family as shown in Fig. 1 (d).

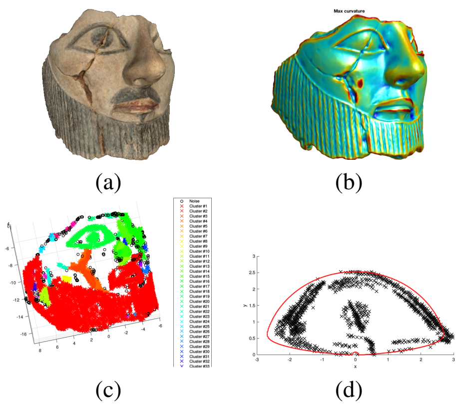

Figure 1: *(a) The model $\mathcal{M}$ of a Salamis terracotta fragment, [STA]. (b) Values of maximum curvature on the model $\mathcal{M}$. (c) Partition of the point set $\mathbb{X}$ into 60 coloured clusters applying DBSCAN. (d) Feature points (in black) and their approximation with a geometric petal curve (in red).*

To grasp compound shapes, it is possible to use different curves. For instance, to extract the eye shape in its entirety we can detect a circumference and successively a geometric petal curve (see Figure 2 (a)), taking advantage of the circumference's position and dimension for restricting the parameters space of the geometric petal curve.

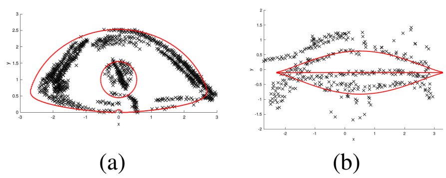

Figure 2: *Combined shapes: (a) a circumference and a geometric petal curve detecting an eye; (b) a citrus curve with a line detecting a mouth.*

Another approach is to define a more structured family of algebraic curves starting from two or more simple families. This is the case of the mouth contour which can be detected combining a citrus curve (a curve deriving from a sextic surface called the *zitrus* (or *citrus*) *surface*) with a line. An example of this detection is represented in Figure 2 (b). This second approach has the clear advantage of simultaneously detecting compound features with the inconvenient of handling more complex families of algebraic curves (that is, defined by higher degree polynomials).

3. Experimental results

The proposed methodology has been tested on a collection of artefacts collected from the STARC repository [STA] and the AIM@SHAPE repository [EC15]. Figure 3 contains images of the chosen models: the models of cases A and B are taken from [EC15], whereas the models of cases C, D, E and F are taken from [STA].

All the models, except model D, are available as triangulated meshes; model D is given as a point cloud set. In the cases A, B and C the colour is not available, so only the geometrical information (via maximum and minimum curvature functions) is used to extract the feature points set. In the remaining cases the geometry is combined with the chromatic information. In all the cases, the models position inside the 3-dimensional space is completely random and a "best" view is artificially reported in Figure 3, columns 1 and 2, for reader's convenience. Further, to lower the computational costs, the number of vertices of the models original meshes is reduced using the MeshLab function *Quadric Edge Collapse (with texture)* [Vis].

Experiments represented in Figure 3 are aimed to the extraction of eyes. The contours of the two eyes are independently detected in the cases A-D. An interesting phenomenon is presented by case D: the values of one of the parameters of the geometric petal curves are nearly the same, meaning that the two eyes heights are approximately the same, whereas a difference can be noticed in the values of the other parameter, which can be ascribed to the partiality of the left eye. The left and right pupils are visible and independently extracted in the cases A and E: the parameters which makes sense to compare are the circumference radii which are approximately the same in each model. Due to faded colours, in models E and F the left eye contours are difficult to be extracted: the geometric petal curves obtained from the right eyes are used to properly recognize the left eye shape (see Figure 3).

It is important to point out how close the parameters of the models E and F are, this suggesting that the proposed method could be used to extract the parameters which characterize a style and that may possibly be employed for eyes' detection on other artefacts of the same collection. As for the cases C and D, we observe that the parameters are not comparable to each other neither to those of A and B since the eyes dimensions are not uniformly scaled.

4. Conclusive remarks

This paper presents a novel method to identify features like anatomical characteristics or decorations in digital artefacts or fragments, even if the features are partially damaged or incomplete. The method can be applied to fragments arbitrarily embedded in the 3D space with the only assumption that the features can be locally projected on a plane. In this way, we have introduced a novel generalization of the Hough transform applied to curves extracted from a set of potentially significant points of the input digital model. The major advantages of this method are the relative robustness to noise, the recognition power in case of partial features and the fact it deals with 3D meshes and point clouds. Another interesting point is the possibility of recognizing compound features, as for the eye contour and the pupil.

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References

[APM15] ANDREADIS A., PAPAIOANNOU G., MAVRIDIS P.: Generalized digital reassembly using geometric registration. In *Digital Heritage* (2015), vol. 2, pp. 549–556. 1

[Bal81] BALLARD D. H.: Generalizing the hough transform to detect arbitrary shapes. *Pattern recogn. 13*, 2 (1981), 111–122. 1

[BMP13] BELTRAMETTI M., MASSONE A., PIANA M.: Hough transform of special classes of curves. *SIAM J. Imaging Sci. 6*, 1 (2013), 391–412. 1, 2

[BR12] BELTRAMETTI M., ROBBIANO L.: An algebraic approach to Hough transforms. *J. of Algebra 37* (2012), 669–681. 1

[EC15] EC: The Shape Repository. http://visionair.ge.imati.cnr.it, 2011–2015. 3, 4

[EKSX96] ESTER M., KRIEGEL H. P., SANDER J., XU X.: A density-based algorithm for discovering clusters in large spatial databases with noise. In 2^{nd} *Int. Conf. Knowledge Discovery and Data Mining* (1996), AAAI Press, pp. 226–231. 2

[HT11] HARARY G., TAL A.: The Natural 3D Spiral. *Comput. Graph. Forum* (2011). 1

[Koe84] KOENDERINK J. J.: What does the occluding contour tell us about solid shape? *Perception 13*, 3 (1984), 321–330. 1

[KST08] KOLOMENKIN M., SHIMSHONI I., TAL A.: Demarcating curves for shape illustration. *ACM Trans. Graph. 27*, 5 (2008), 157:1–157:9. 1

[MPCB15] MASSONE A. M., PERASSO A., CAMPI C., BELTRAMETTI M. C.: Profile detection in medical and astronomical images by means of the hough transform of special classes of curves. *J. Math. Imaging Vis. 51* (2015), 269–310. 2

[Pey] PEYRE G.: Toolbox graph - a toolbox to process graph and triangulated meshes. http://www.ceremade.dauphine. fr/~peyre/matlab/graph/content.html. 2

[PPY*16] PINTUS R., PAL K., YANG Y., WEYRICH T., GOBBETTI E., RUSHMEIER H.: A survey of geometric analysis in cultural heritage. *Comput. Graph. Forum 35*, 1 (2016), 4–31. 1

[Shi95] SHIKIN E.: *Handbook and atlas of curves*. CRC, 1995. 2

[STA] STARC repository. URL: http://public.cyi.ac.cy/starcRepo/. 2, 3, 4

[TB14] TORRENTE M.-L., BELTRAMETTI M. C.: Almost vanishing polynomials and an application to the Hough transform. *J. of Algebra and Its Applications 13*, 08 (2014), 1450057. 2

[TWW01] TANAKA J., WEISKOPF D., WILLIAMS P.: The role of color in high-level vision. *Trends in cognitive sciences 5*, 5 (2001), 211–215. 2

[Vis] VISUAL COMPUTING LAB – ISTI – CNR: Meshlab. http://meshlab.sourceforge.net/. 3

[YBYS08] YOSHIZAWA S., BELYAEV A., YOKOTA H., SEIDEL H.-P.: Fast, robust, and faithful methods for detecting crest lines on meshes. *Comput. Aided Geom. Des. 25*, 8 (2008), 545–560. 1

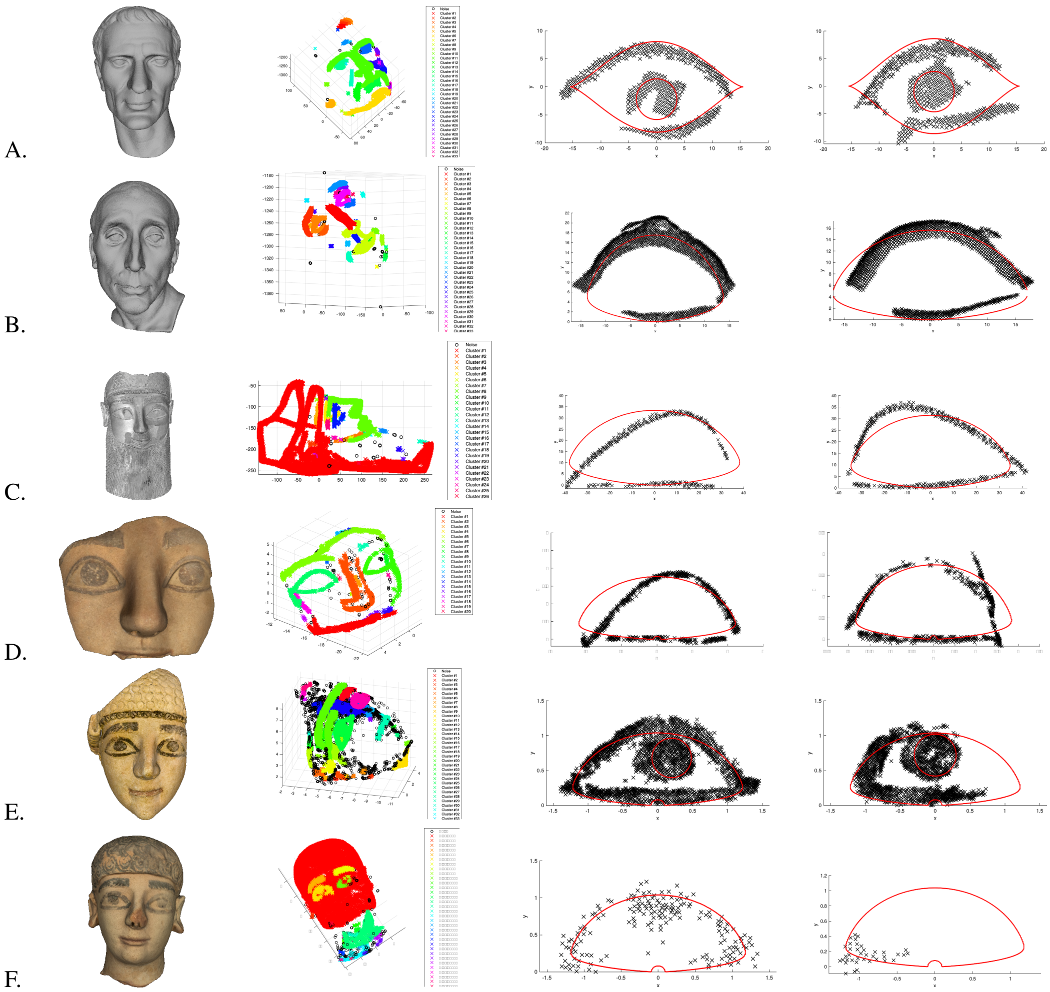

Figure 3: *Detection of eye contours and pupils on collection of artefacts collected from the STARC repository [STA] and the AIM@SHAPE repository [EC15].*