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Geometric invariance in digital imaging for the preservation of cultural heritage in Tunisia

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ABSTRACT

Here, we intend to apply the harmonic analysis approach developed for the formulation of the invariant shape description for the 2D and 3D reconstruction of dynamic scenes. This formulation allows us to extract relevant descriptors which are invariant relatively to a given group of geometrical transformations. Such geometric invariance with respect a class of transformations provides to the reconstruction algorithms more robustness and better precisions compared to the conventional ones. In 3D case, the geometric invariance serves to refine 3D model generated by “shape from silhouette” algorithm. In the other hand, the registration algorithms which are based on the invariance approach allow the creation of panorama image mosaics from uncalibrated images. We illustrate the importance of the described methods in the context of cultural heritage preservation in Tunisia.

1. Introduction

The computer vision techniques are increasingly used for the more recent cultural heritage preservation systems. Ideas are numerous such that the contribution to the creation of virtual museums, the e-tourism and the semantic web. Such applications involve 3D scanning of valuable monuments, the collections of historic objects, the panoramas of archaeological sites, virtual Tours or monuments and so on.... In this paper, we will introduce two novel approaches based on invariance theory for panorama construction and the reconstruction of 3D models.

The virtual tours and the panorama reconstructions become among the most popular solutions for distant and virtual consultation of historical monuments. These applications make monuments accessible to experts such as archaeologist or art historians, and even to the large public. Image registration is a crucial step in the construction of panoramic images and the creation of high-quality mosaics. There are two traditional approaches to classify different registration methods: the dense (also called iconic) and the sparse (also called geometric). Inthe dense method all the pixels in the transformed image have the same geometric transformation. Fourier Phase correlation is an interesting technique suitable for global transformation estimation. On the similarity group, Analytical Fourier Mellin Transform (AFMT) phase correlation allows rotation and scale factor estimation. Also, on 3D rotation group, Spherical Fourier Transform (SFT) phase correlation is used to estimate 3D rotation.

The principle of sparse methods consists generally in matching specific points or geometrical structures in order to have enough equations to determine the mathematical transformation between the two images. To match key points, invariant parameters are measured directly from images and used as shape descriptors which are unchanged for different viewpoints. Such descriptors could be AFMT descriptors or SFT descriptors. In the mosaicing application, we will establish the relationship that links two images using AFMT descriptors to match points of interest.

Creating digital gallery of museum's collections is also an interesting issue in virtual museum application. Among the 3D modeling approaches, two main groups are to be distinguished: active and passive. Active methods use a 3D scanner and require a controlled source of light such as a laser or a coded light in order to recover the 3D information. Passive methods require only the information contained in the scene images. In this last kind of approaches, the only input data to the algorithm is a set of images, possibly calibrated. 3D image-based modeling is becoming more and more popular since recent techniques provide highquality models. “Shape from silhouette” techniques are especially interesting since they offer good initial model for further processing in 3D reconstruction algorithms. Here we propose touse a finite set of viewpoints and to compute invariant shape descriptors in order to refine 3D model. Such descriptors could be computed on external contours subscribing shape. Here we will use Affine Invariant Fourier Descriptors (AIFD) to characterize shape among changing viewpoints.

Geometric invariance is a property which remains unchanged under

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an appropriate class of transformations. Complete and stable invariant descriptors could be a function which represents the shape of the observed object. Whether, it is a curve, a surface or a grey level volume. Many applications such as computer vision, medical imaging, and speech recognition use the invariant features to name a few. The main classes of geometrical transformations of interest are Euclidean, Affine and Projective.

Here, we intend to use geometric invariance in a novel way in two topics: To assist standard 3D reconstruction techniques for a better quality model and in the "mosaicing" techniques for the construction of panoramic image mosaics.

Thus, the present paper will be organized as follows: In the first section, we begin by describing the principal methods of the 3D reconstruction techniques as well as creating panoramas methods. In the second section were call the shape representation approach based on the generalized harmonic analysis formulations. The third section will be dedicated to, some real archaeological applications for Tunisia country.

1.1. *Digital imaging for cultural heritage preservation*

Tunisia's landscape is peppered with historical monuments. These pertain to diverse civilizations spanning 3,000 years, from entire ancient settlements to shrines, amphitheaters, bathing houses, churches and cenotaphs. Phoenicians, Romans, Vandals, Byzantines, Spaniards, Turks, and the French have each left an imprint on the nation's storied terrain with well-preserved sites and intriguing age-old ruins at every turn. It is also possible to visit the world's largest collection of Roman polychrome mosaics at Tunisia's national museum and archaeological repository, The Bardo Museum. People flock from all over the world to visit the city of Carthage, a great Phoenician trading empire during the 6th century given its strategic location at the mouth of the Gulf. In addition of Carthage, lists of 45 sites and monuments have been officially inscribed as UNESCO World Heritage Sites. Creating a virtual museum aims at highlighting the historical value and could be used in the service of cultural tourism. In this context, we are focusing in two kinds of applications: creating panoramic images for virtual tour and reconstructing 3D models.

Creating digital gallery of museum's collections is an interesting issue in virtual museum application. In addition, such digital contents can be viewed through the internet from anywhere in the world, without moving objects or visiting sites. 3D models can be created by a graphic designer using specialized tools such as 3D Studio Max or Maya. However, the required work to obtain a good quality model makes the entire process very long and expensive. Active techniques which use laser range scanning (Levoy et al., 2000) or structured light have a number of drawbacks, namely the need for specialists, expensive hardware and also the requirement of repeated handling of fragile object for substantial period of time. Image-based modeling has the advantage to below cost and to produce high quality models that can be textured later. The difficulty of defining a proper 3D reconstruction system, which works for a large class of objects, explains the abundant research that exists on this subject. Image-based techniques can be classified on three broad classes (Slabaugh et al., 2001): geometric intersections, color consistency, and pair wise matching.

First class is known as "shape from silhouette" or "volume intersection" (Starck et al., 2006). This method use a finite set of viewpoints, and compute what we will call the inferred "visual hull" (Laurentini, 1994). Typically we start with a set of source images that are simply projections of the object onto N known image planes. Each of these N images must then be segmented into a binary image containing foreground regions to which the object projects; everything else is background. These images are known as silhouettes images. If these silhouettes are then back-projected into 3D space and intersected, the resultant volume is the visual hull of the object. Obviously, this requires us to know where the camera was relative to the object when the picture was taken, which is known as a calibration problem.

"Color consistency" or "Voxel Coloring" method (Seitz and Dyer, 1997) uses pixel color to distinguish surface points from other points in a scene. The algorithm begins with reconstructing volume of initially opaque voxels that encompasses the scene to be reconstructed. As the algorithm runs, opaque voxels are tested for color consistency and those that are found to be inconsistent are carved. The algorithm stops when all the remaining opaque voxels are color-consistent. These final voxels form a model that closely resembles the scene.

"Pairwise matching" is a method that relies upon the challenging task of robustly matching features between image pairs. These methods (Scharstein and Szeliski, 2002; Strecha et al., 2003) use normalized cross correlation of all image points along epipolar lines or matching local features (contours, regions…) which also leads to a sparse reconstruction based on the same kind of data. One should consider the first kind of matching better since it produces dense 3D data, but these are unstructured 3D data that need to be structured afterwards. Besides, feature based algorithms also produce sparse reconstruction but the feature itself gives a structure to the reconstruction (especially high level features such as contours or regions).

Panorama is a key area of interest in cultural heritage preservation. In addition, such digital contents can be viewed through the internet from anywhere in the world, without moving objects or physically visiting sites.

An image mosaic is a collection of images taken from different angles of view and reduced to a single mark. As stated in Derrode and Ghorbel (2001), we can classify the methods of creating mosaics into two categories: dioptric and catadioptric. In the dioptric methods, only refractive elements (lenses) are used while in the catadioptric methods, some reflective elements (mirrors) will be added. Among the dioptric methods, we can find sets of cameras, panoramic lenses (Ghorbel, 1994), "fish-eyes" lenses (Oppenheim and Lim, 1981), linear cameras (Zitova and Flusser, 2003) or more conventionally rotating cameras. In the catadioptric methods, we usually find a camera attached to a conical (Fischler and Bolles, 1981), spherical (Cohen et al., 1989), parabolic (Bartoli et al., 2003) or double curvature mirror. We will discuss in this paper a new dioptric method for the creation of images mosaic. We will use the pinhole camera model whose projection center coincides with the center of rotation. Under ideal conditions, we can establish the relationship that links two images which is an homographic transformation (Bevilacqua et al., 2005). There are several ways to determine the matrix of homographic transformation. It is also possible to determine the coefficients of the homography which describes the intrinsic and extrinsic parameters of the two images' shots, or extract the parameters of shots from the image itself and from the previously obtained images. Therefore, we have a problem of image registration to solve. To reconstruct panoramic images, we use a sparse registration algorithm based on AFMT phase correlation. We calculate the phase correlation between the neighborhoods of keypoints. From the value of phase correlation, we can know the key points that correspond. Sparse methods follow, for the most part, the following scheme:

1. Detection of interest points in both images.
2. Matching points.
3. Optimization Algorithm.
4. Transformation Estimation.

To summarize, in the domain of panorama construction, we have exposed the most popular techniques. AFMT phase correlation, as new dioptric mosaicing technique, can use sparse registration or dense registration. The choice of registration method depends on the nature of geometric transformation between transformed image and template image. In the context of similarity transformation, it is possible to do dense registration using the AFMT phase correlation. For more general transformation as homography, and using the AFMT phase correlation,