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Original article

Recording and documenting the chromatic information of architectural heritage

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ABSTRACT

One essential approach in preserving architectural heritage is the documentation of 3D geometries and surface textures of historic buildings. For example, precise colour information, excluding lighting effects, is an intrinsic property of the surface materials of building interiors and exteriors. However, while colour information has been recorded for small sample areas, it has not been accurately documented on the scale of entire building surfaces. This is critical, because building materials decay and their colours fade with time. The goal of this project is to develop a method to assist in recording and documenting the chromatic information of interiors and exteriors of historic buildings with low cost and high efficiency. The method takes advantage of emerging high dynamic range imaging (HDRI) technology, which can store rich information about colour and illumination through digital photography. By recording the colour information, in addition to the geometry and texture information obtained through other existing technologies, we can achieve more complete documentation for architectural heritage. In this paper, we discuss an overview of the problem and present our algorithms for utilizing computer vision techniques to retrieve chromatic information of historic buildings. We also present and discuss our experiments and results of applying our method to studies of lab objects and the Hall of Supreme Harmony in the Forbidden City, Beijing.

1. Introduction and research aims

One essential approach to preserving historic buildings is documentation. With the advance of digital technologies, digital documentation, including digital photography, digital photogrammetry, and 3D laser scanning, has been used successfully for documenting historical architecture [1]. These digital technologies assist in documenting the 3D geometries and surface textures of historical buildings. However, another identifying feature of historic buildings, intrinsic colour information of interior and exterior building materials, has not been accurately documented on the scale of large building surfaces. The intrinsic colour of materials is determined by the physical properties of light absorption, reflection, and emission spectra of the surface materials, but is not affected by lighting conditions. Colour information is important, as the materials of historic buildings are decaying and their colours are fading. Fig. 1 demonstrates the significant lacquer colour fading on buildings in the Forbidden City, Beijing.

Existing methods in colour documentation include:

(a) manual observation;
(b) archive study and research;
(c) paint analysis.

Paint analysis is a scientific analysis of architectural finishes and their colours. The analysis procedure includes collecting samples, performing microscopic analysis, and matching the colours identified to the Munsell System of Colour Notation, an industry standard for colours. A recent review of paint analysis using cross-section microscopy techniques and colour matching is found in [2]. Paint analysis consists of taking numerous samples on building surfaces – from 15 to 20 per room or elevation, depending upon the details of the historic buildings [3,4]. More accurate analysis requires a larger number of samples to be examined [3] (for more information about paint research, see [5,6]).

These methods are frequently used in combination with one another. For example, manual observation of colours, together with archival research to retrieve the original colours of historic buildings, has been used in preservation projects, including the Ewa Plantation Revitalization Project on the island of Oahu in the Hawaiian Islands [7]. Welsh presented a method in [8] combining (1) archival study, using a 1902 newspaper article and interior and exterior photographs about the building in preservation – the Florida State Capitol; and (2) paint analysis, using microscopic analysis of original finishes. The paint colours were finally matched

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Fig. 1. Three photos showing 'colour decay' on historical buildings in the Forbidden City, Beijing: (a) recent repainting during a major renovation of the Forbidden City before the 2008 Beijing Olympics; (b) colours starting to decay; (c) significant colour degrading.

to the industry standard for colours. Matching colours identifies original paint colours and recommends restoration finishes [9].

The aims of the research presented in this paper are to:

(1) research an effective and efficient new method using computer vision techniques to document existing colour information, excluding external lighting conditions, of the interior and exterior surfaces of historic buildings;
(2) develop a prototype of the method to test and validate it. In addition, we expect the digital colour documentation to assist in the process of paint analysis (although the method's purpose is not to reveal paint layers).

The significance of the research lies in the following aspects:

1. the method assists with documenting surface colours of the current state of historic buildings. Colours on both small and large surfaces can be retrieved with automatic image processing on photographs of historic buildings;
2. documentation of historic buildings can provide important information on buildings' significance for use by researchers, preservationists, and others interested in preserving and understanding historic buildings [10]. Digitizing the colour information, in addition to the geometry information that can be acquired by other means, is a step toward complete documentation;
3. the method can be used to model surface colours to reflect the present conditions of historic buildings and assist in the education about cultural heritage;
4. the method could potentially be used for monitoring and detecting the colour change (i.e., colour fading) of historic buildings if the recording and measurement are done on a regular basis;
5. the method can assist in automatic classification of colour regions to facilitate efficient sampling in paint analysis by reducing the number of samples required for analysis. The method can also help identify representative colour regions where samples can be extracted;
6. the novelty of the research includes:
   (1) the application of computer vision techniques to solving a cultural heritage problem – recording and documenting the chromatic information of historic architecture,
   (2) an original, time- and exposure-varying image processing method that utilizes both existing image processing algorithms (e.g., high dynamic range [HDR] radiance maps and segmentation), and a novel method integrating a time-varying shadow removal technique and an exposure-varying imaging technique for recording colours in HDR, which are critical aspects of the process for documenting chromatic information.

This paper presents an overview of the subject's background (Section 2), related work (Section 3), our methods (Section 4), experiments (Section 5), discussion (Section 6), and conclusion (Section 7). Please note that throughout the paper, the term "colour" refers to the intrinsic colour property of surfaces, excluding external lighting effects such as shadows and highlights.

2. Background and problem statement

2.1. Digitization of historic buildings

The existing framework for historic reconstruction involves surveying, historic investigation, 3D digital modelling of buildings and an enabling (multimedia) interface [11]. To attach colour textures, one method is to use a point-wise sensing device to densely sample the site and attach colour textures from a digital camera separately, and another method is an image-based approach to reconstruct the model with colour texture automatically attached [12].

Laser scanners can acquire a large number of 3D points that can be used to reconstruct the 3D models of buildings, and image-based techniques provide a fast approach to digitizing with cameras [13]. In addition to geometric data collection, surface colour mapping is important in the area of cultural heritage to facilitate complete documentation. Some commercial 3D systems already provide model-registered colour texture by capturing the RGB values of each light detection and ranging (LIDAR) point using a camera integrated in the system [14]. However, frequently, these camera-captured images are not sufficient for high quality texturing, because the ideal conditions for taking the images may not coincide with those for laser scanning [15]. Also, the limited dynamic range of the images prevents users from obtaining correct texture information under varied lighting conditions.

2.2. High dynamic range imaging

Research has been undertaken using computer-aided monitoring of buildings of historical importance based on colour [16], the purpose of which, however, was to use colour-based image processing technology to aid detection of material decay, instead of digitizing and documenting colours of surfaces.

Devices like spectrophotometers can be used for colour measurement in general, but they are limited to measuring a small sample area (3 to 26 mm) at a time. This makes it not applicable for measuring large areas like architectural interiors and exteriors. Thus, developing a technology to assist in documenting surface colour information about historic buildings becomes necessary.

Colour photography is able to record colour information of large surfaces to a certain extent. However, it cannot be applied directly to documenting precise, intrinsic colour information of the surfaces. The reasons include: