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Development of Modern Methods for the Diagnostics of Murals in Architectural Monuments

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***Abstract**:*

The paper studies monitoring of the state of murals, retrieval of data pertaining to this state and management and storing of the said data. The possibility of integration of traditional methods of mural mapping and modern methods of data visualization, including new Google Project Tango device technology for fixation of complex textures of inner 3D volumes of architectural monuments has been investigated (for instance Assumption Cathedral).

We further discuss the express-scanning of automated cartogramming for further comparison of states and methods of assessing the damage done to the mural. Results indicate that additional work is needed to improve the precision of the method.

***Keywords:** Archaeology, Frescoes, Cultural heritage, Defectoscopy, Architectural monument, 3D visualisation, Project Tango, Infrared sensor, SLAM, SFM, PTAM, Structure from motion, Monocular vision, Stereo vision.*

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1. Introduction

One of the most important and difficult tasks of monitoring the state of cultural heritages is observation of decaying murals. At this moment fixation of subject compositions and its consists of graphical and photometric fulfillment which cant be automated. This aspect seriously complicating monitoring the state of cultural heritages with difficult painted architectural elements of interior.

Cartogramming of ancient murals is a process of creating full copies of all of paintings of explored temples not in separate fragments but whole copy in form of unwrapped walls of the room fully colored with considering accurate scale of all of parts of painted interior (Krylov and Krylova 1998).

The method of fixating story and state of mural havent really changed since the end of XIX century. It consists of manually creating schematic widescale black-and-white images of the main elements of murals on the semi-transparent paper. But this method has series of disadvantages. First of all, the scheme is created in one instance for one mural story without snapping to the architectural elements of building. Also on one cartogram there are all defects of the painted canvas at exact point of time in which they were done which makes it hard to decoding.

Using of photometry restricted to photo fixation of murals. Huge quantity of artistic details of murals makes it hard to read the defects in order to analyze the state of paintings. In this way, all of the methods above dont allow to monitor changes of painted canvas with the aim of detection risks and menaces in order to create ensuring conservation event. Optimal way of solving this this problem is periodically cartogramming murals with universal systematized representation in time. In this work use of synthesize of classic method with computer technologies is proposed. Method of regular monitoring the state of the murals with fixation of their state allows to optimize the work of restorer and to estimate the scale of restoration and examination works.

2. Materials and Methods

1. Google Project Tango

1.1. Google Project Tango

There is no doubt that smartphones with the support of Google Project Tango technology are the discovery of 2016. Those devices, beside the unique Intel RealSense Camera ZR300, have common for the smartphones cameras: front 8 megapixels and back 2 megapixels. On the back surface (see Fig. 1), from left to right, there are:

- Right infrared camera;
- Color camera;

- Infrared laser projector;
- Left infrared camera;
- Short-focus wide-angle camera for movement detection. Common camera (with its' accompanying flash) ZR300 is designed for the external world filming. Laser projector lays the infrared grid on pointed objects. Two infrared cameras capture the picture. Dimensional objects' characteristics are calculated with the method of pixel shifting during the image analysis, captured from left and right infrared cameras. Speed processing of the space's depth is 10 million dots per second.

Besides that, smartphone includes wide-angle camera with VGA resolution and visual angle of more than 160 degrees, with which high-precision combination of accelerometer and gyroscope operates. That kind of complex is called gyrostabilizer (Inertial Measurement Unit, IMU). This camera is used for observation of moving objects and scene's properties.

Project Tango provides mobile industry with three basic technologies:
1) observation of moving objects; 2) exploration of the surroundings; 3) preservation of space's depth.

Technology of movement observation uses gyrostabilizer to locate the device based on its' movement starting point. An approach like that can be used for navigation indoors without using GPS. The Simultaneous Localization and Mapping (SLAM) (Davison & Murray, 1998) method is used to the study the environment, which was originally developed from Structure-from-Motion (SFM) (Tomono, 2005) method. The core of the SLAM lies in the uniting the data of scanned space and tracking the location. This can be used for "offset corrections" in the scenario where movements tracking is being completed during sufficiently long periods of time.

1.2. Comparison Of The Approaches of SFM, SLAM and PTAM

SFM solves the problems of reconstructing 3D scenes from small sets of images, and projective geometry is used as a method of constructing scenes. SLAM performs real-time motion estimation, and the environment is continuously monitored by sensors that can turn cameras on or off. SFM- and SLAM-approaches have been studied in recent years (Strasdat, Montiel & Davison, 2016). The technology of perception of the depth of space involves the use of a camera to create a cloud of points representing information about the depth of space and the location of various objects in front of the camera.

The development of the SLAM approach is described in (Davison, 2003), where probabilistic filtering was used to track the change in the position of an object in real time. In (Klein & Murray, 2007), (Klein & Murray, 2008), a SLAM-based learning approach based on SFM was implemented, called PTAM (Parallel tracking and mapping): mapping and tracing are divided into two separate tasks and are performed in parallel threads. Recently, the PTAM algorithm has been widely used in some imaging systems (Stühmer et al., 2012), (Newcombe & Davison, 2010) and robotic systems (Blösch et al., 2010), (Weiss et al., 2013), (Sheng et al., 2011). In (Forster et al., 2017), (Forster et al., 2014), (Engel et al., 2015), a visual odometry algorithm is proposed, which differs somewhat from PTAM. In (Jia et al., 2016), the analysis of PTAM has been continued with the aim of developing this approach.

1.3. Examples of using Project Tango for fast 3D recreation of surrounding environment :

1. *Kastner Research Group*: One example (Gautier et al., 2016) of usage of Project Tango was examined for the visualization of internal volumes of architectural monuments and for creating highly realistic 3D models with detailed textures. Traditionally, archaeologists use deprecated method of creating a 3D model on the paper with a pencil. This method falls behind in comparison with using modern technologies, because visualization with this method becomes implicit. Automatic 3D-reconstruction provides higher precision and details of fixated images placed on the internal volumes of architectural monuments (murals, painting, icon).
2. *CHISEL*: In the paper (Klingensmith et al., 2015) describes the process of development of system CHISEL. It is a system for highly realistic 3D reconstruction in real time with dynamic spatial hashing (Nießner et al., 2013), depth map (Davison and Murray, 1998) and visual-inertial odometry for accurate localization. CHISEL authors avoid unnecessary calculations and excessive memory usage by discarding out parts of the scene that do not contain surfaces. However, CHISEL can not yet guarantee the tracking of the integrity of the global map and the accumulation of positioning errors over time (“drift correction”). Many previous works (Stueckler et al., 2014), (Nießner et al., 2014) combined the mapping of some key points, visual odometry and preliminary reconstruction in order to reduce the accumulation of errors. It is noted that future researches should adapt SLAM methods combining visual inertia odometry, sparse landmark location and dense 3D reconstruction in a more efficient way to ensure real-time relocation on a mobile device.
3. *Personal Indoor Mapping*: In the article (Gülch, 2016) it is proposed to use devices equipped with the Tango Project for cartographic applications for researching rooms with reduced accuracy requirements in order to compete with high-level instruments such as tachometer, ground-based laser scanners or short-range photogrammetric cameras.

2. Methods for state of architectural monuments murals estimation

One of the important tasks for monitoring the safety of cultural heritage sites (or “CHS” for short), and in particular the state of artistic images (murals) of the interior surfaces of architectural monuments. Temperature-humidity regime of architectural monuments observations were started only in the 70s of the last century. Those monitorings in most monuments with murals were carried out by recording the temperature and relative humidity of the indoor air and comparing these data with the parameters of outside air for a certain period. An evaluation of its state (Sizov, 1982), (Devina et al., 1985), (Gordeev et al., 1990) was the nature of the changes in these measurements. Also an indirect indicator of the temperature-humidity condition of structures, including materials of murals, is their microbiological evaluation (Sizov, 2003).

Following the rules of museum storage, many experts still assume the identity between the microclimate within the monument and the temperature-humidity condition of its structures, without any objective, quantitative data on their actual state. Nowadays the state of the monument can be often assessed only at the stage of visible destruction of the surface layer of murals visually with the use of microscopy or special types of photography.

One of the main reasons for this "visual-superficial" approach to assessing the state of preservation of the monuments structures and physically connected with them murals (Sizov, 2003) calls "insufficient dissemination of non-destructive methods for assessing the humidity state of materials of architectural monuments".

3. Results and Discussions

Copying of ancient Russian painting, the creation of complete cartograms (Krylov & Krylova, 1998) temple murals are the only methods in the preservation of church painting of the national restoration school until recently. The cartogram of ancient murals is the creation of complete copies of all murals of the investigated temple not in separate fragments, but entirely in the form of scans of the walls of the room, made in color with an exact account of the scale relationships of all parts of the painted interior. Traditional methods of cartogram making of murals are described in (Petrusenko, 1998).

While developing an automated system for monitoring architectural monuments (Shaykhutdinova *et al.*, 2015), (Shaykhutdinova *et al.*, 2016) the authors faced similar problems in linking cartograms to the real geometry of CHS (Kasimov *et al.*, 2016) and methods for their evaluation. At the moment, for all significant CHS there are archives of cartogram mural paintings, which nevertheless do not have a clear binding to their internal geometry.

Using the proposed Google Project Tango technology for the rapid assessment of the state of the CHS mural paintings (Appendix A), we can distinguish the following tasks performed at all stages automatically and *in situ* (in situ – is a Latin phrase that translates literally to "on site" or "in position"):

1. Scanning the internal geometry of the CHS.
2. Obtaining a preliminary 3D model.

3. Parallel withdrawal of textures.
4. Process of cleaning of the received data (geometry and textures) from noise, using low-frequency and / or median filters.
5. Linking textures to the 3D model.
6. Cartography of murals from cleaned textures.
7. Binding of early archival cartograms to the obtained geometry.
8. A comparison of the fresh cartogram with the archived ones with the help of calculations of the root-mean-square deviations.
9. Identification of problem areas reflecting the greatest change in state;
10. An estimation of percent of losses.
11. Archiving obtained data and taking it to a remote server.
12. Dynamics of problematic places on the obtained quantitative express-characteristics.

For purposes of archival of cartograms obtained at different periods of the CHS assessment we can use method for automatic processing of large collections of documents, including their validation and semantic analysis, this we won't cover in this paper.

3.1. Evaluation of loss percentage

The loss is estimated on three independent registration channels: the brightness of RGB channels of the optical camera, the IR camera data and the depth map, which makes it possible to increase the representativeness of the results obtained.

The algorithm for identifying problem areas for one channel is as follows: at the initial stage, the received current defect inspection map is applied to the archive reference and their normalization is performed both in geometric and amplitude characteristics by means of affine transformations, brightness adjustment and contrasting for optical data of possible individual filters for each of the color-bearing channels. If necessary, the images are cleared from interference by low-frequency and/or median filters. The next step is to calculate the root-mean-square deviations for each point in the entire data set. When the threshold values of root-mean-square deviations are exceeded, the coordinates and amplitudes of the places taken for the problematic are written to a separate file or layer for the possibility to further observe the dynamics of destruction and to make decisions for each specific case. Both the change in the area of the problem areas and the increase in the standard deviation from the standard one will indicate the constant nature of the changes (destruction) and the need to take measures to prevent further degradation of the problem areas.

The quantitative express-characteristics of problematic areas can be the percentage of the affected area and the maximum root-mean-square deviation. It is possible to use the histogram method (Zykov *et al.*, 2013), (Zykov *et al.*, 2008) as an express-analyzer.

A generalized scheme for processing scanning maps using the histogram method. Thus, schematically the processing algorithm of the obtained maps can be described by the following order of procedures and cycles:

1. Normalization of the image in the amplitude range.
2. Bring the brightness characteristics to the standard form.
3. Contrasting the image.
4. Combine the object on the reference points.
5. Construction of control histograms.
6. Affine transformations.
7. Median filtering.
8. Low-pass filtering of the image.
9. Histogram express analysis of images in X and Y coordinates of the grid.
10. Filter histograms.
11. Allocation of "problem" places according to the maxi mum standard deviation of histograms.
12. Recording of problem coordinates in the database.
13. Automatic processing of the received data of the express analysis (if necessary, attraction of the user for decision-making in the form of a choice from the offered variants).
14. Repeat the previous items for each luminance and infrared channels.
15. Summary record of the received information.
16. Similarly, defectoscopy is performed for the other inde pendent recording channels.

4. Conclusions

High-quality spatial data of high density, which can capture a pair of infrared cameras, can be used for three-dimensional scanning of indoors for building depth maps and reconstruction of captured scenes. The wide-angle camera, the gyrostabilizer and the calibrated sensor synchronization software programs allow the device to realize the capabilities of Google Project Tango, in particular, for fast two-band 3D defectoscopy of architectural monuments, automating the process of monitoring complex textured objects with significant accuracy of fixing flat images on internal surfaces dimensional architectural elements.

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Appendix A. *Scheme of 3D defectoscopy of murals module pro*