PhD Topic Proposition for 2018-2021

Hosting laboratory : Laboratoire Systèmes et Applications des Technologies de l'Information et de l'Energie (SATIE)
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Historical music instrument 3D reconstruction and wear detection in UV-induced fluorescence photography

Thesis detailed overview The study of historical music instruments provides crucial information about the relationship between an instrument morphology and its acoustic properties. The results are useful both for researchers and for contemporary violin makers. Our group is currently exploring a collaboration opportunity with the Arvedi Laboratory of Non-Invasive Diagnostics of University of Pavia located at Museo del Violino in Cremona, home to some of the most outstanding Stradivari, Amati and Guarneri violins.

Digital 3D models of these violins are needed for multiple reasons. Firstly, accurate dimension measurements are generally taken by a curator with high-precision calipers in specific locations, and a 3D model would allow to readjust easily the measurement locations when needed, or to measure different distances. The use of laser scanning has been studied [1], but the procedure is tedious (up to six hours) and difficult due to the instrument shape and to manipulation restrictions. At the same time the laser theoretical precisions is deteriorated by the presence of the highly-reflective varnish coating. Thus, a first aim of the work is to create an accurate 3D model on two 360° sequences of RGB and UV-induced fluorescence images of the object, which would be useful in a first step to provide core measurements of the instrument while avoiding a cumbersome procedure. Compared to a classical multiple-view-stereo reconstruction, this problem differs by the availability of two modalities (the RGB and UVF images). On the one hand these different modalities provide complementary information cues (useful for instance to remove ambiguities), on the other hand both of them present high (but not simultaneous) specularities. Since the high re-emission properties in UV lighting of the areas lacking the varnish coating allow for the estimation of the instrument wear, there is a need to discriminate robustly between wear-related areas and specularity phenomena (detrimental for 3D reconstruction) for the various view-points available. Then, in the reconstruction we propose to model these types of ambiguities in terms of compound hypotheses, in the sense of belief function theory. Now, these ambiguities add to the classic ambiguities in feature matching processes that result in sparse, irregular 3D point clouds in the preliminary step of a reconstruction. Then, we will take advantage of a third data source, namely a generic instrument model. Beside providing a potentially decisive prior in the low textured areas, the model will allow us to infer jointly the light source location and to dispose of a reliable prior for the presence of specular reflections.

A second interest of processing the image sequences is that currently the identification of varnish wear is performed in single frontal (specularity free) views [2, 3], while the possibility of using multiple views should allow for a more comprehensive characterization of the wear. However, current analysis strategies based on a decision tree applied to HSV values and coupled to morphological filtering, or on HSV histogram quantization would not work as soon as significant specularity occurs. On this point, the multi-view inference supported by the specularity detection performed at the reconstruction step should allow us to detect more accurately the borders and the degree of wear at the surface of the instruments (see Figure 1 for wear estimation in a frontal view, and interfering specularity phenomena).

Finally, the adoption of multimedia and multi-modal applications inside museums and exhibitions is becoming a common practice, and adapted Augmented Reality scenarios need to be identified in order to explain scientific analyses conducted on artworks to the general public. In this case the possibility to manipulate a digital model would allow for displaying the rich information related to the variability of each unique artwork morphology (shape, dimensions), or the wear levels. In the field of cultural heritage, some recent works explored the problems related to overlaying multiple modalities, and to displaying information provided by experts. For example, a path we will explore is the work of [4] which studies how to project in 3D and superpose reliably expert information provided in individual 2D views. In our case, the experts would be replaced by the automatically detected wear cues from individual views. Then, the work of [5] proposes osmosis filtering to transfer information from one modality to another ; this concept could be used in order to blend seamlessly the wear information from the UV channel into the RGB views which are more adapted for artwork visualization.

Objective As explained in the PhD overview, three objectives are aimed :

FIGURE 1: a) Varnish wear estimation based on the **UV fluorescence** (image adapted from [2] : RGB image, UV image and wear estimation map overlaid on the UV image ; b) Specularity in the 360° sequence (visible light) ; c) Specularity in the 360° sequence (UV lighting).

- definition of a method allowing for 3D reconstruction of violins from multiple views acquired in visible and in UV lighting ; a generic shape of the instrument can be assumed as prior information.
- localization and identification of varnish wear from multiple views, and particularly from those acquired in UV lighting.
- use of the obtained 3D model of the instrument in Augmented Reality scenarios, for instance allowing the visitors to visualize individual or composite wear estimation maps, or to take some specific measures of instrument dimensions and compare them.

Context The context of this study is given by its specific application. While some methods have already been proposed for 3D reconstruction, such as based on tomography measures (among the numerous techniques already proposed) to only quote one of the most famous [6, 7, 8], in the case of historical instruments, the strict transportation and handling protocols of these instruments prevent the customary use of such techniques. Beside the affordability concerns, another limitation of most techniques, including tomography, is that although they may provide rich information about the condition of the internal parts, the information related to the outer surface layers is limited. Now, this is mainly the part of the instrument affected by wear. Among the lighter techniques (not requiring the instrument transportation), the laser scanning is currently used. But the procedure is tedious (up to six hours) and difficult due to the instrument shape and to manipulation restrictions. Then, the applicative context of this work imposes the use of RGB and UV-induced fluorescence images of the object, which would be useful in a first step to provide core measurements of the instrument while avoiding a cumbersome procedure.

In terms of methodology, the context is the solid background in the domain of 3D reconstruction from multiple-view classical images as well as more and more works that aim at taking into account the local imprecision and uncertainty of the measurements in the considered estimation problem. Indeed, when well modeled, this allows for automatic adaptation to the actual information content of the data. Then, in this work, due to the specific application that involves non-stationary ambiguities in the data, we aim to introduce uncertain reasoning model in 3D reconstruction.

Methods We propose to formulate our problem as a double problem linking the 3D reconstruction with the identification of varnish wear. Indeed, as previously stated, since varnish worn out areas can have similar color as specularities, their identification for the 3D reconstruction is required. On the other hand, the 3D model allows for predicting possible specularities and then for distinguishing them from varnish wear.

First, in order to initialize the 3D reconstruction, we will rely on a typical MVS framework [9, 10, 11], which will not cope with highly-reflective surfaces. The generic 3D prior model is used to densify the first guess through an approximate registration.

Now, to model the imprecision and the uncertainty of the wear estimation, we rely on uncertain reasoning framework, namely the belief function theory [12, 13, 14]. Different formulations of the problem can be considered. The first one, the simplest, will use an evidential grid such that, in each cell of the grid, a belief function is defined and handled. It represents the belief in any hypothesis of the powerset of the discernment frame that in our case includes some hypothesis about the wear presence, the specularity effect, etc. Beside the primary interest for the wear estimation itself, a key point is that this belief function also allows for the estimation of the reliability of the matching for the 3D reconstruction. An alternative modeling will consider a discernment frame that is the 3D space itself and formulate hypotheses about the localization of each different phenomenon (varnish wear, specularity). Until recently such a discernment frame would be intractable to handle in the case of belief functions (that are defined on the powerset of the discernment frame). However, we have recently [15] provided a well-defined framework and efficient tools to consider belief functions defined from a 2D discrete discernment frame, namely the 2D space considered in a localization application (of people in a crowd). In this study, [15] work will be extended to the 3D space.

Then, localization of the wear and other relevant photometric phenomena (either directly or on a grid) will allow us to define a specialized reliability index used to guide the data association in the different images for the 3D reconstruction, as well as the weight of the 3D prior model with respect to the multi-view images. Typically, the problem may be approached as an optimization based on the minimization of an energy functional where the data term accounts for the localization of the photometric phenomena, while the regularization term incorporates the generic model prior. While many variations are available based on some fundamental algorithms [16], we intend to rely on a framework based on loopy belief propagation [17], which has the merit of being very flexible and greatly benefiting from acceleration on parallel architectures, and which has been used in the group [18] and accelerated on GPU with excellent results. Once identified, specularities are typically dealt with as outliers, although some works showed that under some additional assumptions they may be used as well in order to extract the local structure [19, 20].

Finally, as previously stated, localization is both uncertain and imprecise, so that the consistency of the 3D reconstruction can be also used to raise ambiguities in an iterative process alternating wear/specularity estimation and 3D reconstruction.

Expected collaborations We intend to collaborate closely with Piercarlo Dondi, postdoctoral researcher in the Arvedi Laboratory. Our group has already been provided violin imagery required for the study. Although it is not imperative for the student to work physically in the museum, we intend to involve as much as possible our colleagues from Italy in the PhD work and we have sufficient own resources for missions. However, in case of a successful application the student would be eligible to apply for mobility programs which support precisely this type of collaborative work, such as the Franco-Italian Program Galilée [1] (for the current call, one of the selected topics is *heritage and innovation*).

Prerequisites Research Master degree with strong background in computer vision and computer graphics.

Skills Image processing and machine vision. Experience with color image processing, 3D cloud point processing, 3D sparse and dense reconstruction, augmented reality. A good level in C++ programming.

[1] P. Dondi, L. Lombardi, M. Malagodi, and M. Licchelli, “3d modelling and measurements of historical violins,” ACTA IMEKO, vol. 6, no. 3, pp. 29–34, 2017.

[2] ——, “Automatic identification of varnish wear on historical instruments : The case of Antonio Stradivari violins,” Journal of Cultural Heritage, vol. 22, pp. 968–973, 2016.

[3] P. Dondi, L. Lombardi, C. Invernizzi, T. Rovetta, M. Malagodi, and M. Licchelli, “Automatic analysis of uv-induced fluorescence imagery of historical violins,” Journal on Computing and Cultural Heritage (JOCCH), vol. 10, no. 2, p. 12, 2017.

[4] T. Messaoudi, P. Véron, G. Halin, and L. De Luca, “An ontological model for the reality-based 3d annotation of heritage building conservation state,” Journal of Cultural Heritage, 2017.

[5] S. Parisotto, L. Calatroni, and C. Daffara, “Digital Cultural Heritage imaging via osmosis filtering,” in International Conference on Image and Signal Processing, 2018.

[6] A. Mathys, J. Brecko, and P. Semal, “Comparing 3d digitizing technologies : what are the differences ?” in Digital Heritage International Congress (DigitalHeritage), 2013, vol. 1. IEEE, 2013, pp. 201–204.

[7] S. A. Sirr and J. R. Waddle, “Use of CT in detection of internal damage and repair and determination of authenticity in high-quality bowed stringed instruments,” Radiographics, vol. 19, no. 3, pp. 639–646, 1999.

[8] B. Frolich, G. Sturm, J. Hinton, and E. Frolich, “The secrets of the Stradivari string instruments. a non-destructive study of music instruments from the Smithsonian Institution, the Library of Congress, and private collections. a pilot study of seven violins made by Antonio Stradivari in Cremona, Italy, between 1677 and 1709,” Ann Arbor, MI, USA, Washington, DC (March 2009), 2009.

[9] M. P. Deseilligny and I. Cléry, “Apero, an open source bundle adjusment software for automatic calibration and orientation of set of images.”

1. https://www.campusfrance.org/fr/galilee

[10] P. Moulon, P. Monasse, and R. Marlet, "Global fusion of relative motions for robust, accurate and scalable structure from motion," in Computer Vision (ICCV), 2013 IEEE International Conference on. IEEE, 2013, pp. 3248–3255.

[11] J. L. Schönberger and J.-M. Frahm, "Structure-from-motion revisited," in Conference on Computer Vision and Pattern Recognition (CVPR), 2016.

[12] G. Shafer, A Mathematical Theory of Evidence. Princeton university press Princeton, 1976, vol. 1.

[13] P. Smets and R. Kennes, "The transferable belief model," Artificial Intelligence, vol. 66, no. 2, pp. 191–234, 1994.

[14] T. Denoeux, "40 years of dempster-shafer theory," International Journal of Approximate Reasoning, vol. 79, pp. 1–6, 2016.

[15] N. Pellicanò, S. L. Hégarat-Mascle, and E. Aldea, "2cobel : An efficient belief function extension for two-dimensional continuous spaces," in 21st International Conference on Information Fusion, 2018.

[16] R. Szeliski, R. Zabih, D. Scharstein, O. Veksler, V. Kolmogorov, A. Agarwala, M. Tappen, and C. Rother, "A comparative study of energy minimization methods for markov random fields with smoothness-based priors," IEEE transactions on pattern analysis and machine intelligence, vol. 30, no. 6, pp. 1068–1080, 2008.

[17] J. S. Yedidia, W. T. Freeman, Y. Weiss et al., "Generalized belief propagation," in NIPS, vol. 13, 2000, pp. 689–695.

[18] N. Pellicanò, E. Aldea, and S. Le Hégarat-Mascle, "Geometry-based multiple camera head detection in dense crowds," in Proceedings of the 28th British Machine Vision Conference (BMVC) - 5th Activity Monitoring by Multiple Distributed Sensing Workshop, 2017.

[19] A. C. Sankaranarayanan, A. Veeraraghavan, O. Tuzel, and A. Agrawal, "Specular surface reconstruction from sparse reflection correspondences," in Computer Vision and Pattern Recognition (CVPR), 2010 IEEE Conference on. IEEE, 2010, pp. 1245–1252.

[20] C. Godard, P. Hedman, W. Li, and G. J. Brostow, "Multi-view reconstruction of highly specular surfaces in uncontrolled environments," in 3D Vision (3DV), 2015 International Conference on. IEEE, 2015, pp. 19–27.