ULP — Université Louis Pasteur Strasbourg

Résumé de la thèse

Summary of Ph.D thesis

Discipline : Computer science

Presented by : Frédéric Larue

Title : Digitization of art pieces in terms of shape and appearance for the purpose of realistic rendering in computer graphics

Research unit : UMR 7005
LSIIT

Thesis director : Jean-Michel Dischler

Grade Location : Professor
ULP

Introduction

For many years, digital archiving has become a major preoccupation in many fields, thanks to the developpement and the popularization of computer tools. The field of art is particularly concerned by this phenomenon, due to some obvious reasons of patrimony preservation, but also for communication and diffusion of cultural heritage. Indeed, many museums are nowadays unable to exhibit the entirety of their collections, and the use of realistic digital copies of art pieces is then of a great interest.

In this goal, a digitization requires the capture of two main data : the shape, on one hand, and the appearance, on the other hand, this latter being absolutely essential for a realistic display on a computer screen. We then tryed to solve some of the multiple problems which arise from the various steps of the whole digitization pipeline, so as to produce a digital copy suitable for real-time rendering.

In particular, we developped a new protocol unifying in a single manipulation the capture of both data. This protocol enables the automation of tasks which required, until now, some manual interventions. Moreover, it only involves very simple and mobile devices, thus allowing measurements *in situ* instead of in laboratories, but without the heavy calibration constraints generally required by such devices.

The visualization of the produced digital copies is also addressed, in the specific case of art pieces captured whithin fixed lighting environments, in a goal of realistic and real time rendering. Good rendering performances are achieved thanks to a very simple model of surface light fields which can be evaluated by the graphics hardware. We also have extended principles of surface fields to perform the plausible interactive simulation of a complex optical phenomenon, namely refringency of translucent materials.

At last, we studied a concrete case with the digitization of art paintings, which led us to establish a specific processing pipeline dedicated to this kind of objects. Some of their particularities enabled us to avoid several problems which classically occure in the general case.

Unified acquisition of shape and appearance

Concerning shape, there exists currently many technologies enabling to recover a digital description of the geometry of an object. However, these tools are still subject to many constraints, preventing them to be fully autonomous. Particularly, they are not able to acquire the whole surface of an object in a single acquisition. It must be done piece by piece, each one being defined into its own local frame. The problem of aligning these surface pieces with respect to each other must then be considered.

Concerning appearance, this is not just a simple colour that is to be captured but a complex photometrical information depending on the lighting environment and on the viewpoint. We placed ourselves in the simpler case of an object acquired within a fixed lighting environment, that is to say that the only variations induced by the viewpoint changes are considered. Nevertheless, even in this case, the acquisition consists in an exhaustive sampling of the viewing directions, requirering numerous pictures taken from different viewpoints. These pictures must then be merged with the geometry so as to produce an exploitable digital copy.

One has then to address two distinct problems of *registration*, the first one being purely geometric, and the second one involving both 2D and 3D data. But, in both cases, the first step of the solution (and, of course, the less obvious) consists in establishing correspondences between the different datasets. We developped a digitization protocol in order to solve both registration problems in an automatic manner, and by using the same basic principle : a structured light range scanner is used to project a luminous parameterization over the considered object, enabling to get back direct correspondences between the digitized part of the surface and a picture taken from an external camera, focused on the same object. Picture-to-geometry registration can then be performed, and to make geometrical registration possible, the external camera acts like a fixed reference between two successive scanner positions.

Our studies have shown that all registration problems can be solved in a reliable and fast manner with only these two devices (scanner + external camera) and our protocol.

Automation of geometry denoizing

Digitization, like any measurement, being subject to uncertainty, the gathered information is necessarily noisy. These perturbations can be corrected by applying filters over the geometry. The more efficient filters for this purpose are the *adaptive filters*, which adapt the correction strenght depending on the surface local behaviour. This allows to preserve the small geometrical features compared to more standard filters, which generally make them disappear. However, these specific filters often require some additional information about the noise parameters. These parameters are generally not known, and can only be determined in an empirical manner, after many successive attempts.

We then proposed a new approach in order to estimate these parameters by exploiting redundancy of the input data. Noise, by nature, being random, averaging several measurements of the same surface naturally tends to make its influence disappear, thus approaching the perfect theorical surface. Since geometrical registration necessarily requires some overlapping between the different surface pieces, such a redundancy is always available after a digitization procedure. Overlapping areas can then be denoized in a reliable manner by a judicious exploitation of the redundant information.

In order to extend denoizing to the whole surface, we used these overlapping areas, whose correction result is known, to estimate the parameters of some existing adaptive filters taken from the litterature. This allowed us to avoid manual interventions during the filtering process of digitized 3D meshes.

We also proposed our own filtering algorithm, and a method for surface merging based on the erosion/remeshing principle, which preserves the initial data and chooses the best sampled measurement in the overlapping areas.

Interactive and realistic rendering

After all the registration steps, the data associated to the art piece appearence are composed of a lot of color samples (many tenths, or many hundreds) per geometrical primitives. From the visualization side, this represents data that are too dense to be straightforwardly exploited during the rendering. Moreover, if the reconstructed models are destined to be aimed through media like the Internet, as in our case, compacity of the final digital copies is a relevant factor.

This information must then be compressed by using some representation model which respects following criteria. First of all, it cannot be too destructive so as to preserve the visual quality. Moreover, if a direct evaluation by the graphics hardware is desired for better performances, this model must also be simple enough. We chose a polynomial texture representation, here adapted to *surface light fields*. The model, even if quite basic, turns out to be efficient enough to give a realistic effect to digitial copies thanks to the capture of major illumination phenomena.

Our main contribution in the visualization field is to have extended surface fields in order to simulate the refraction phenomenon. We proposed to represent this phenomenon by using a distortion field over the surface, which encodes for each incident viewing ray the direction of the output ray. This field is estimated beforhand during a preprocessing step, thanks to a ray tracing algorithm, and compressed in the frequency domain of spherical harmonics. Decompression is performed on the fly by the graphics hardware, thus leading to a real-time rendering. We have shown that our method, even if heavy in terms of memory consumption, enables a good approximation of the refraction phenomenon where other methods might fail due to complex geometry.

Processing pipeline dedicated to art paintings

The digitization process is made of a complex chain involving, as we just talked about, several processings. We have focused on designing dedicated techniques in order to simplify (or to suppress) some of these processings, thanks to the specific properties of some kinds of objects. We then proposed a complete protocol for the digitization and the visualization of art paintings.

Considering the planar shape of paintings, a single acquisition is sufficient for the complete digitization, thus avoiding geometrical registration problems. Moreover, if geometry is contained within a single acquisition, it is possible to work directly on the resulting range image by using some more simple image processing tools.

All the processings we proposed lead to a segmented canvas separated from the remaining of the painting. This segmentation isolates areas where the relief of the canvas is significant enough to require a visualization technique which really accounts for it (like *impastos* for knife painting).

Two rendering algorithms are then used : a simple one for the canvas part considered as negligible, and another one for the segmented part, which exploits the graphics hardware to visually simulate correct reliefs without requiering the true geometry. The second one being more computationally costly, we set up an adaptive mecanism which allows to use it only when the viewing conditions require it, in other words when the parallax errors become too significant.

This method leads to high rendering speed and only uses small and very compressible files to represent the digital copies (including a bidirectionnal texture), particularly because geometry does not need to be stored.

Conclusions and future works

Most of our works were focused on the automation of the different steps which make the digitization process really tedious. The addressed topics are covering the whole pipeline, from the acquisition itself up to the realistic visualization of the digital copies. Intended to art pieces, the proposed solutions were designed to account for the fragility of such objects. Considering the complexity of the whole digitization pipeline, we have also pointed out the benefits of dedicated methods, by developping a complete protocol for the digitization and the visualization of art paintings.

Following these works, there are still many directions that need to be explored. In the short term, we would like to extend our digitization protocol to allow one the acquisition of a full bidirectionnal texture, that is to say by accounting for the variations in appearance induced by the lighting changes too. A scanner prototype has already been built for this purpose. Such a texture could be acquired without requirering extensive modifications of the existing protocol, thanks to the five light spots fixed on this device.

In the long term, we would like to design a digitization system completely interactive, able to localise in real time a light source from the only information visible by the external camera. This would allow one to move the source by hand and to immediately check if the sampling of incident lighting directions is dense enough.

Publications and communications

International conferences with reviewing process and publication of proceedings :

- Frédéric Larue, Lucas Ammann et Jean-Michel Dischler. "A pipeline for the digitization and the realistic rendering of paintings". *Proceedings of VAST 2007 : the 8th International Symposium on Virtual Reality, Archaeology and Cultural Heritage*, pages 71–78, 2007.
- Frédéric Larue et Jean-Michel Dischler. "Automatic registration and calibration for efficient surface light field acquisition". *Proceedings of VAST 2006 : the 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage*, pages 171–178, 2006.
- Olivier Génevaux, Frédéric Larue et Jean-Michel Dischler. "Interactive refraction on complex static geometry using spherical harmonics". *I3D'06 : Proceedings of the 2006 symposium on Interactive 3D graphics and games*, pages 145–152, 2006.

International conferences without reviewing process :

- Jean-Pierre Chambard, Vincent Chalvidan, Mohammed Tazeroualti, Frédéric Larue, Jean-Michel Dischler, Virginie Vurpillot et Anne-Claire Legrand. "Digitization of art pieces based on 3d, colour and texture parameters". *Proceedings of SPIE Symposium on Optical Metrology*, volume 6618 - O3A : Optics for Arts, Architecture, and Archaeology, 2007.

National conferences without reviewing process :

- Frédéric Larue, Lucas Ammann et Jean-Michel Dischler. "Chaîne de traitement pour la numérisation et le rendu réaliste de peintures d'art". *Journées de l'Association Française d'Informatique Graphique*, pages 73–81, 2007.
- Frédéric Larue et Jean-Michel Dischler. "Recalages et calibrages automatiques pour l'acquisition de champs lumineux surfaciques". *Journées de l'Association Française d'Informatique Graphique*, pages 171–178, 2006.