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Ph.D thesis on Digital Holography

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Thesis topic

Holographic video coding with motion estimation and compensation
Keywords: Holography, Data compression, Video coding, 3D video

Job description

> Scientific context

With the recent advances in capture and display systems, immersive technologies attracted a considerable attention from the scientific and industrial communities during the last decade. As a matter of fact, consumers seek for a better sensation of presence during their remote interactions and audio-visual entertainments: there is a strong desire for the ultimate Star Wars-like three-dimensional (3D) display able to project the user into an immersive and realistic virtual environment or to give the illusion that interlocutors from miles away are present in the same conference room.

Unfortunately, most current 3D visualization systems – such as Head-Mounted Displays (HMD) or 3D televisions – are based on Stereoscopy, which fails to create a natural and realistic depth illusion. Indeed, it does not reproduce all the Human Visual System (HVS) depth cues perceived in natural vision. In particular, it cannot provide the accommodation stimulus: the viewer has to focus on a fixed plane whose depth does not match the actual location of perceived objects. This severely degrades interaction and immersion, and creates the so-called Vergence-Accommodation Conflict (VAC), leading to eye-strain and headaches.

To solve this limitation, several alternative technologies have been proposed in the last decades. Among these techniques, Holography is often considered as the most promising one, since it provides all the HVS depth cues without causing eye-strain. To create the depth illusion, a hologram diffracts an illuminating light beam to give it the shape of the light wave that would be emitted, transmitted or reflected by a given scene. As a consequence, the viewers perceive the scene as if it were physically present in front of them.

Thanks to its attractive visualization properties, Holography is a perfect candidate for the ultimate 3D display, creating virtual images indistinguishable from the real ones. However, it presents several open issues which need to be tackled. One of the most important obstacles is the massive amount of information contained in a digital hologram. Indeed, since it creates the depth illusion using light diffraction, the pixel pitch of a hologram should be close to the wavelength of visible light. Because of this microscopic size, a hologram with a large size and wide viewing angle contains several billions of pixels, leading to terabytes of data. For instance, a hologram of size 20cm × 15cm with a viewing angle of 120° requires a resolution of 720K × 540K pixels, involving more than 1TB per frame. Even taking into account the rapid evolution of electronics technologies, storing and transmitting such a huge amount of data is far from being achievable in the next few years. From this observation, it is clear that novel compression algorithms able to significantly reduce the memory and bandwidth consumption of holographic signals are needed.

The main challenge for data compression lies in the fact that holograms are essentially 2D diffraction patterns having very different signal properties compared to conventional images and videos. In particular, they contain high-frequency coefficients which play a major role in 3D visualization and cannot be discarded as in typical image coding techniques.

In light of this, several compression techniques were specifically designed for holographic data. Nevertheless, most of these works were focused on static holograms without taking into account temporal redundancies in holographic videos. Indeed, automated motion estimation from holographic data is still an open issue that has never been solved. Removing temporal redundancies would significantly reduce the memory and bandwidth consumption of holographic videos. It is thus envisioned that future coders will require this feature.

To fill this gap, the objective of this thesis is to design a new generation of holographic video coders featuring motion estimation and compensation for several independently moving objects. Breaking with conventional compression techniques, the student will use bridges between the Geometrical Optics model, describing light rays, and Fourier Optics theory, modeling the propagation of light waves, to understand and characterize the connection between scene objects' motions and the evolution of holographic fringes.

> Objectives of the thesis

To automatically estimate and track motion in the scene, one has to extract and analyze 3D content variations from the holographic signal. Unfortunately, retrieving the scene from a single digital hologram is an inverse ill-posed problem for which no exact solution exists in the literature. Indeed, the light wave scattered by each scene point contributes to every pixels during hologram recording. As a consequence, the holographic signal scrambles the 3D scene information, which cannot be straightforwardly retrieved. In particular, a slight change in the scene translates to substantially different hologram patterns, making motion estimation a very challenging research topic.

To achieve this challenge, two research paths will be investigated in parallel. The first approach is to use space-frequency analysis tools to retrieve the scene from holographic fringes. Then, scene objects motions will be estimated and compensated from this extracted data. In the second approach, the student will try to estimate and compensate scene deformations by only considering the evolution of holographic fringes. In particular, he will investigate non-trivial transforms to directly represent the space-frequency evolution of the hologram in a compact closed form. Finally, the designed algorithms will be accelerated and parallelized into computationally efficient implementations.

Who we're looking for

- Master or Engineer's degree in Signal/Image processing, Applied Mathematics or equivalent
- Competences in Artificial Intelligence (deep learning, neural networks, etc.)
- Comfortable with C++ and Matlab languages
- Proficient in English, spoken and written

Terms

- Fixed-term contract
- Start date: October 2021
- Duration: 3 years
- Location: Rennes