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Compressive multiple view projection incoherent holography

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Short summary: In this seminar, the principles of the multiple view projection (MVP) holography technique are given. After understanding the principles, the intuition of the paper is shortly given. Finally, the new technique so called compressive multiple view projection (CMVP) holography is presented and the numerical simulations are also demonstrated.

I. Introduction

1. Holography is a classical method to store three dimensional information of a scene.
2. Acquisition methods of traditional holography are required high coherence and high powered sources such as lasers.
3. Without using the sources, the multiple view projection (MVP) holography technique is proposed.
4. The authors have pointed the drawback of the MVP holography technique, and then they have remedied the drawback by adopting the compressive sensing (CS) approach.

II. The Multiple View Projection (MVP) Holography Technique

1. According to the paper, the MVP holography technique appears to solve the traditional Holography technique that requires the sources such as lasers.

2. The process of the MVP holography technique:

   A. While a digital camera moves, it captures many view of the same scene from different angles.

   B. Each captured scene is projected into the CCD plane.

   C. Then, the different projections are used to synthesize a digital hologram.

3. Any ordinal digital camera can be used to store a three dimensional information of a scene.

4. The drawback of the MVP holography technique requires a significant scanning effort.

   A. For example, to generate a hologram whose size is 256×256, $256 \times 256 = 65536$ projections are acquired.

5. To remedy the drawback, techniques [Rosen07][Kim10] have been proposed.

   A. The first one is to employ a lenslet array instead of the CCD plane. But, this approach gives a low resolution hologram. [Kim10]

   B. The second one is to reduce scanning times by recording only a small number of the projections and synthesizing the rest using a view synthesis stereo algorithm. But, this approach faces with some difficulties in handling multiple scenes. [Rosen07]

   C. Please, read the papers if you have interested in them (They are not covered in this seminar). According to the authors, the proposed technique in this paper remedies the drawbacks presented in the papers.

6. The process of obtaining a digital hologram using the MVP technique is divided into optical and digital stages according to the paper.

   A. In the optical stage, different perspectives of the scene obtaining from a digital camera are recorded.

i. The perspective can be characterized by a pair of angles (φ_m, θ_n).

ii. The $(m,n)^{th}$ projection is denoted to $p_{mn}(x_p, y_p)$, where x_p and y_p are the coordinates in the projection domain.

B. In the digital stage, we multiply each acquired projection by a complex phase function $f_{mn} = \exp\{-j2\pi b(x_p \sin\varphi_m + y_p \sin\theta_n)\}$, where b is a real constant.

C. Obtaining a Fourier hologram. It is done by integrating the product of p_{mn} and f_{mn} as following: $h(m,n) = \iint p_{mn}(x_p, y_p) f_{mn} dx_p dy_p$. Then, we obtain a complex scalar for every projection (φ_m, θ_n).

i. By taking a Fourier transform on $h(m,n)$, we will get a reconstruction which corresponds only to $z = 0$ plane of the scene.

ii. In general, to obtain a reconstruction corresponding to z_i, we should multiply the hologram by a quadratic phase function. Viz.

$$u_i(x,y) = \mathcal{F}^{-1}\left\{h(v_x, v_y)\exp\left[-j\pi\lambda z_i\left(v_x^2 + v_y^2\right)\right]\right\}, \quad (1)$$

where u_i is the reconstructed plane, both v_x and v_y indicate spatial frequencies, λ denotes the central wavelength and $\mathcal{F}$ represents the Fourier transform.

D. Since digital holograms are considered, (1) becomes

$$u_i(x,y) = \sum_m \sum_n h(m,n)\exp\left\{-j\pi\lambda z_i\left[(\Delta v_x m)^2 + (\Delta v_y n)^2\right]\right\}\exp\left\{j2\pi\left(\frac{mp}{N_x} + \frac{nq}{N_y}\right)\right\}, \quad (2)$$

where N_x and N_y are the number of pixels in the x and y directions respectively. For simplicity, $N_x = N_y = N$. (2) can be rewritten as a matrix-vector multiplication form as following:

$$\mathbf{u}_i = \mathbf{F}^{-1}\mathbf{Q}_{-\lambda^2 z_i}\mathbf{h}, \tag{3}$$

where $\mathbf{u}_i$ is a $N^2 \times 1$ vector corresponding to z_i plane. Let F be a $N \times N$ discrete Fourier transform matrix whose elements are $F_{m,p} = \exp(-j2\pi mp/N)$. Then, $\mathbf{F} = F \otimes F \in \mathbb{C}^{N^2 \times N^2}$, where $\otimes$ is the Kronecker product. The matrix $\mathbf{Q}_{-\lambda^2 z_i} \in \mathbb{C}^{N^2 \times N^2}$ is a diagonal matrix with quadratic phase elements along its diagonal.

E. Shortly, reconstructing $\mathbf{u}_i$ is easy. $\mathbf{F}$ is given, $\mathbf{Q}_{-\lambda^2 z_i}$ is determined the angles, and $\mathbf{h}$ is obtained by integrating the product of p_{mn} and f_{mn}.

F. To understand how to get $\mathbf{h}$ from an experiment, we need to read the following papers.[Rosen01][Rosen03]…

III. Compressive Sensing approach for reducing the number of projections

1. The idea is very simple and intuitive.
   A. To reconstruct a hologram, what things do we need? They are $\mathbf{F}$, $\mathbf{Q}_{-\lambda^2 z_i}$ and $\mathbf{h}$.
   B. Among them, what is the measured factor in an experiment? It is $\mathbf{h}$.
2. The authors assume that the synthesized Fourier hologram $\mathbf{h}$ can be sparse. Then, this assumption allows us to reduce the size of $\mathbf{h}$. It is the main idea of this paper.

3. Let us denote $\mathbf{h}^M$ to the subsampled Fourier hologram. By solving the below equation

$$\hat{\mathbf{u}}_i = \arg\min_{\mathbf{u}_i} \left\{ \left\| \mathbf{u}_i - \mathbf{F}^{-1}\mathbf{Q}_{-\lambda^2 z_i} \mathbf{h}^M \right\|_2^2 + \gamma \left\| \Psi_i \mathbf{u}_i \right\|_1 \right\}, \tag{4}$$

we can reconstruct an object plane $\mathbf{u}_i$ at distance z_i from $z=0$ plane. In the paper, the authors recommend Ψ_i such as Haar wavelet or total variation and the authors name it compressive multiple view projection (CMVP) holography.

IV. SUMMARY OF THE CMVP HOLOGRAPHY

1. Instead of $N^2 = N_x \times N_y$ projections, only $\Omega(K \log N)$ random projections of the scene are taken.
2. Multiply each taken projection p_{mn} by its corresponding phase function f_{mn}.
3. Then, we get a single Fourier hologram by doing $h(m,n) = \int\int p_{mn}(x_p, y_p) f_{mn} dx_p dy_p$.
4. After obtaining an under-sampled Fourier hologram $\mathbf{h}^M$, we can reconstruct each plane of the scene by solving (4).

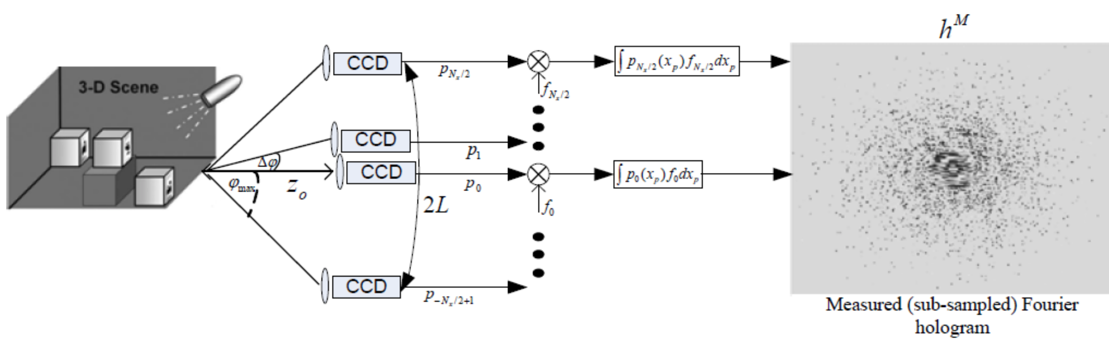
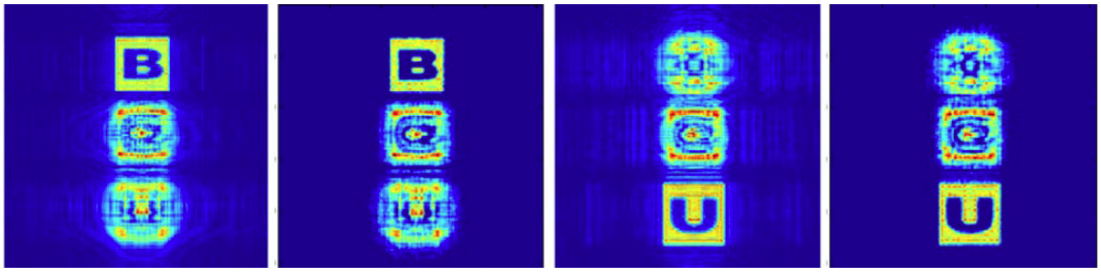


Fig. 1. Illustration of CMVP hologram acquisition. Acquisition of only $\approx K \log N_x$ projections results in a heavily undersampled Fourier hologram. Each sample in the hologram plane corresponds to a nonuniformly randomly picked projection.

In the above Fig. 1, the CMVP hologram acquisition is shown. For simplicity, only a scan along the *x*-axis is shown. The minimal angular distance between two adjacent projections is $\Delta\varphi$, and z_0 is the distance between the imaging system and the object. The length of the CCD's translation trajectory is $2L$.

V. NUMERICAL RESULTS



(a) (b) (c) (d)

Fig. 2. Reconstruction examples of the B and U planes of simulated data. (a) Reconstruction of the B plane from 100% of the projections. (b) CS reconstruction of the B plane from 6% of the projections. (c) Reconstruction of the U plane from 100% of the projections. (d) CS reconstruction of the U plane from 6% of the projections.

In both (a) and (c), 256×256 projections are required.

In both (b) and (d), $256 \times 256 \times 0.06$ projections are acquired.

In the CMVP method, Haar wavelet transform is used and TwIST solvers is used to solve (4).

VI. CONCLUSION

1. In this paper, the authors shortly have summarized about the multiple view projection (MVP) holography technique (See Section 2). Then, the authors have proposed the compressive multiple view projection (CMVP) technique (See Section 3).

2. The strong advantages of the proposed technique are that 1) it does not require changing a sensing hardware, 2) it gives a high resolution hologram compared to the previous technique [Kim10], and 3) it does not require a distinct anchor point problem arisen in [Rosen07].

   (In the paper, the authors have made a part System's Resolution Analysis for the theoretical analysis of the system's resolution limit. If you have interested in it, please carefully read the paper)

   (The distinct anchor point problem is that the technique [Rosen07] requires the distinct anchor points to interpolate the different perspectives of the scene. Thus, if the scene is changed, then the distinct anchor points are also changed. However, the CMVP technique is free from this)

VII. DISCUSSION

After meeting, please write discussion in the meeting and update your presentation file.

Reference

[Rosen01] Y. Li, D. Abookasis, and J. rosen, “Computer-generated holograms of three-dimensional realistic objects recorded without wave interference,” Appl. Opt. 40(17), 2864 – 2870 (2001).

[Rosen03] D. Abookasis, and J. Rosen, “Computer-generated holograms of three-dimensional objects synthesized from their multiple angular viewpoints, “J. Opt. Soc. Am. A 20(8), 1537 – 1545 (2003).

[Rosen07] B. Katz, N. T. Shaked, and J. Rosen, “Synthesizing computer generated holograms with reduced number of perspective projections,” Opt. Express 15(20), 13250 – 13255 (2007).

[Kim10] N. Chen, J.-H. Park, and N. Kim, “Parameter analysis of integral Fourier hologram and its resolution enhancement,” Opt. Express 18(3), 2152 – 2167 (2010).