Montecarlo computational proyect: Implementation of DBS algorithm

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In the context of computer generated holography, the generation of binary amplitude holograms is of great interest, as the modulators able to project such holograms have a high refresh rate and are considerable affordable compared to other light modulators. The direct binary search algorithm is an algorithm for generating binary amplitude holograms that is generally considered to produce better results than any similar algorithm, at the cost of being time-consuming. Moreover, the traditional form of the algorithm cannot be accelerated through parallel processing, as its flow depends on the result of past steps. In this work we implement a modification of the direct binary search algorithm that allows the implementation of parallel processing. We use numerical simulations to analyze the effect of this modification on the time required and on the results obtained. We also compare the reduction in time obtained using this method with other alternatives, such as running the traditional algorithm on graphic processing units.

I. INTRODUCTION

Computer generated holography (CGH) is a technique that has been of great interest due to its capability to control optical fields with unmatched precision, allowing the projection of scenes that were not previously recorded [1]. As a result, this technique has become a useful tool in a variety of applications [2–5]. In particular, it has been extensively studied in recent years in hopes of realizing holographic displays that would allow for virtual reality and augmented reality [6].

Despite its potential applications, CGH must overcome its share of challenges. One of these challenges lays in the lack of spatial light modulators (SLM) able to reproduce the holograms generated. There are no SLMs able to achieve full complex modulation without resorting to extremely precise arrangements that make the resulting systems bothersome to work with. As a result, in general one cannot experimentally project the complex holograms that exactly reproduce the desired fields, and computer generated holography is mostly limited to generating amplitude-only holograms and phase-only holograms that can be projected using existing devices [7] to produce approximations of the desired fields.

Another challenge that CGH faces is the speckle noise that arises when using coherent light sources [8]. This is random noise that reduces the quality of the reconstructed image and limits the applications of CGH in potential holographic displays. Some studies have proposed eliminating speckle noise by using partially coherent light sources [9–11], but this approach also reduces the maximum resolution of the reconstructed images. An alternative proposal that does not reduce the maximum resolution is using temporal multiplexing to project multiple holograms with linearly independent speckle noise, so that the overall noise in the registered image is smoothed [12].

The registered speckle noise is reduced as the number of holograms projected through temporal multiplexing increases. However, projecting a high number of holograms in quick succession requires a SLM with a high refresh rate. Among existing devices, binary SLMs offer the highest refresh rates. In particular, binary amplitude SLMs such as digital micro-mirror devices (DMD) exceed the refresh rate of other alternatives by several orders of magnitude [13]. Additionally, these devices are considerable cheaper than other SLMs. As a result, the generation of binary amplitude-only holograms is of great interest for achieving affordable holographic displays that could realize real time holographic video projection with high resolution and image quality through temporal multiplexing.

Binary amplitude-only hologram generation has been extensively studied and many algorithms have been proposed [2–5]. In particular, the direct binary search (DBS) algorithm is generally considered to produce the best results, but it is computationally time consuming [14], defeating the purpose of using it for real-time holographic video projection. Recent studies have proposed modifications to the algorithm that increase its convergence rate and allow for parallel processing, resulting in much lower time requirements [15]. In this study, we implement this modifications of the algorithm and analyze its results as a way to decrease the time requirements.

II. METHODOLOGY

The DBS algorithm is an iterative algorithm for binary amplitude hologram generation, where the flow of each iteration is illustrated in Figure 1. This algorithm receives an initially random binary hologram and analyzes the similarity between the hologram reconstruction on the Fourier plane in region of interest (ROI) and a target complex field. The quality of the reconstruction is measured using a metric that quantifies the similarity between the reconstructed field and the target field. In this study we used mean squared error (MSE) as a similarity metric. The MSE between two complex fields X

and $\hat{X}$ of size $N \times M$ pixels is defined as

$$\mathrm{MSE}(X, \hat{X}) = \sum_{n=1}^{N} \sum_{m=1}^{M} | X(n,m) - \hat{X}(n,m) |^2, \quad (1)$$

where n and m represent the pixels of each field and $|\cdot|$ symbolizes the absolute value. The MSE decreases as the two fields become more similar to each other and the algorithm seeks to optimize the binary hologram by switching the value of an individual pixel to check whether its new reconstruction in the ROI better resembles the target complex field [16]. The pixel retains its new value if doing so improves the reconstruction; otherwise, the change is undone. Each pixel of the hologram is examined in this manner for each iteration of the algorithm.

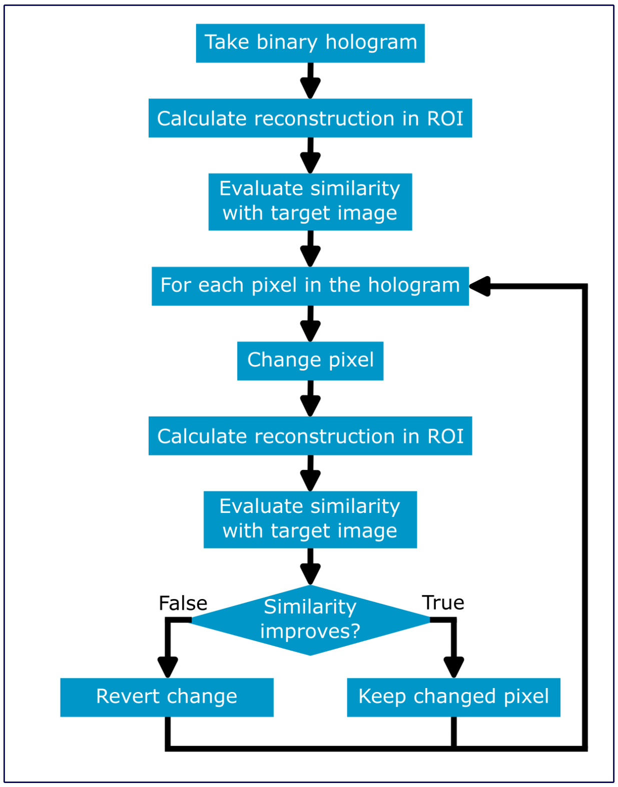

FIG. 1. Flowchart of DBS algorithm. ROI: Region of interest.

The values of the pixels on the hologram are switched in a random order, as this has been reported to produce better results in a lower number of iterations [15]. However, the algorithm in this form is still time-consuming and cannot be accelerated using parallel processing, as the optimization of each pixel depends on the results of the previously examined pixels. One can define a modification of the algorithm that allows for parallel processing by employing the exact complex solution given by the inverse Fourier transform of the desired field. This modification is shown in Figure 2. It is defined as follows: calculate the complex hologram that perfectly reconstructs the target scene and divide it into blocks, then binarize one of the blocks and modify it using the DBS algorithm to optimize the reconstruction of the target scene. This process can be performed independently for each block of the hologram to simultaneously optimize each section of the hologram. Finally the blocks are grouped together to obtain the complete optimized binary amplitude-only hologram.

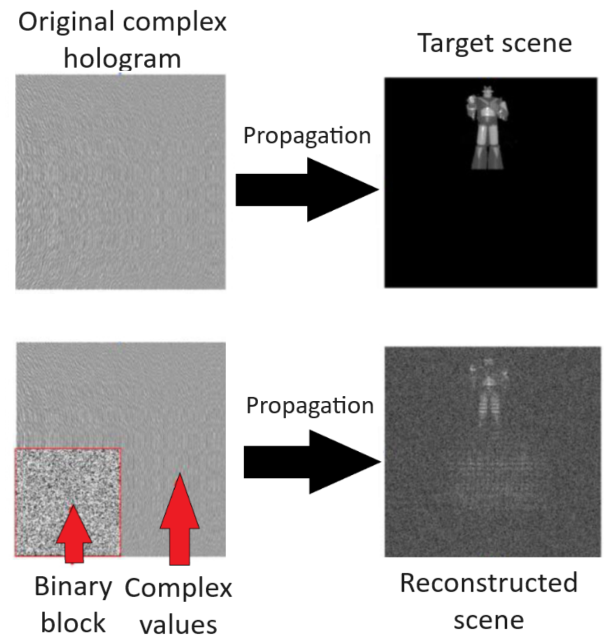

FIG. 2. Modification of the DBS algorithm to allow for parallel processing.

We desire to showcase the complex control enabled by the DBS algorithm and analyze whether the proposed modification affects this characteristic. We also analyzed the effect of the proposed DBS modification on its time requirements and on the final results. We did so by implementing the modified algorithm using different numbers of divisions into blocks to generate a binary 512×512 pixels amplitude-only hologram that reconstructs a 256×512 multiplane hologram. Multiplane holograms are characterized by its ability to generate multiple objects as the field propagates in space, as seen in Figure 3. The 256×512 multiplane hologram was previously generated using CGH algorithms, the first object of the multiplane hologram is generated on the Fourier plane and each subsequent object is generated after the complex field propagates a distance of 1.23 cm. Recovering multiplane holograms requires complex control of the reconstructed field, so retrieving these multiplane scenes would demonstrate the complex control capabilities of the DBS algorithm.

III. RESULTS

These tests were made using an Intel Core i9-13900KF CPU with 24 cores and 32 threads. The 512×512 pixel

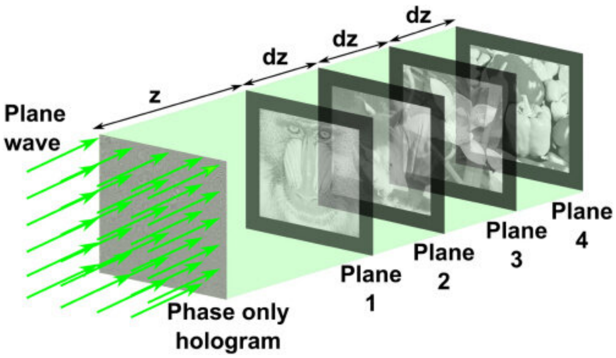

FIG. 3. Example of multiplane hologram [17].

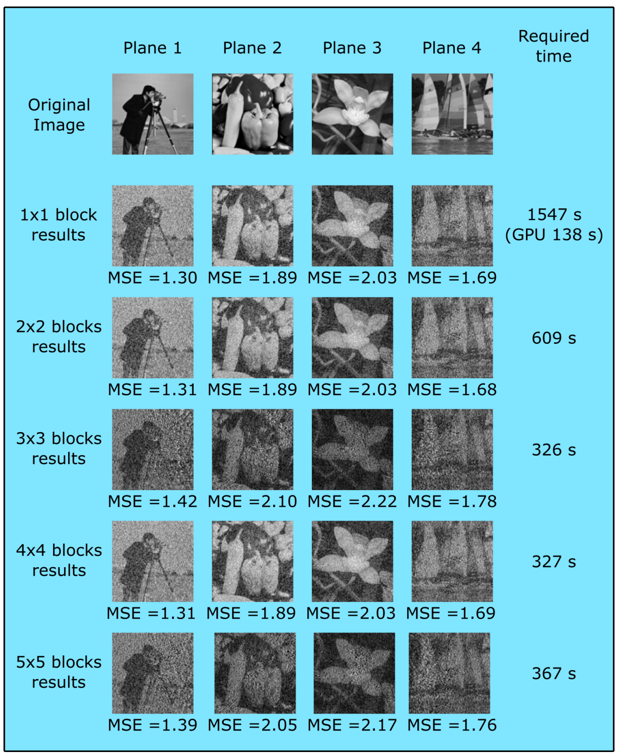

FIG. 4. Results using modified DBS algorithm for different numbers of divisions. All MSEs were divided by 10^5

hologram was divided into 2×2, 3×3, 4×4 and 5×5 blocks before optimizing in order to analyze time required depending on the number of divisions. In cases where the 512×512 pixel hologram could not be divided into blocks of the same size, the remaining pixels were appended to the blocks on the bottom and on the right side of the hologram. We also optimized the entire hologram with the traditional DBS algorithm using both CPU and GPU to compare the results. The GPU used during this test was a NVIDIA GeForce RTX 4090. The results are shown in Figure 4, it includes the final reconstruction in each plane of the multiplane hologram, their MSE with respect to the original images, and the required time for each division.

As it is expected, the time required to complete the algorithm shows a decreasing trend as the hologram is divided into a higher number of smaller blocks. However, dividing the hologram into 5×5 blocks actually increases the required time compared to dividing into into 4×4 blocks, as the number of processes surpasses the number of cores of the CPU in the former case. In each case, the reconstruction of each object was recovered on their respective planes, proving that the modified DBS algorithm allows for complex modulation of a field using binary amplitude-only holograms. However, we see a notable decrease in quality in cases where the 512×512 hologram could not be divided into blocks of the same size. This visual decrease in quality is supported by an increase of the MSE in the respective cases.

The reconstruction quality in the cases where the hologram was divided into 2×2 and 4×4 are very comparable to the case where the entire hologram was optimized using the traditional DBS algorithm. In these cases, employing the modified DBS algorithm produces comparable results in a fraction of the time. However, running the traditional algorithm in GPU is still faster that using parallel processing to run the algorithm in multiple CPU cores.

IV. CONCLUSSIONS

We implemented a modification of the DBS algorithm that allows for parallel processing and used it to generate binary amplitude holograms that reconstruct a multiplane hologram, proving that the modified DBS algorithm allows for complex modulation. The modified DBS algorithm showed an improvement in efficiency compared to the traditional algorithm, as it achieved comparable results in a fraction of the time. However, running the traditional algorithm on GPU rather than CPU showed a greater speedup compared to running the modified algorithm on CPU. Additional speedup could be achieved by using methods to implement parallel processing on GPU.

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