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# COMPARISON OF THE SPEED AMONG DIGITAL, OPTICAL AND HYBRID IMAGE PROCESSORS FOR REAL TIME APPLICATIONS

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## ABSTRACT

Selection of a conventional Digital Image Processor (DIP) / Optical Image Processor (OIP) / Hybrid Image Processor (HIP) depends upon its processing speed. The processing speed is a major constraint to increase the input frame rate which affects the output quality of the real time processing. In this paper, the processing time and maximum input frame rate for real time operation of DIP, OIP and HIP are found out and compared. It is inferred that both OIP and HIP are highly applicable for real time processing whereas DIP is applicable only after reducing their input frame rate.

**KEYWORDS:** DIP, HIP, OIP and Real-time processing.

## 1. INTRODUCTION

In image processing, the emphasis must be given to the term, “Real Time Applications”. If any process is completed within the rate of incoming signal, then it is said to be suitable for real time applications.[1-3] The frequency domain Image processors may be viewed in three broad senses viz, Optical domain Image Processor (OIP) using optics,[4,5] Digital domain Image Processor (DIP) using computers.[6,7] and Hybrid Image Processor (HIP) using both optics and computers.[8,9]

At present, the Digital domain Fourier Transform (DFT) and Inverse Digital domain Fourier Transform (IDFT) in DIP consume much time, in signal/image processing, is a constraint.[10,11] The presence of inherent errors due to sampling, quantizing and aliasing process.[12] in DFT also affects the quality of the output.

The salient feature of Optical domain Fourier Transform (OFT) in OIP is that it produces spectra of given image within a few nanoseconds whereas DFT in DIP produces the same in the order of milliseconds. This is because OFT is a simultaneous process rather than DFT which is under pixel by pixel processing.[13] i.e., the spectra of the entire image can be obtained by manipulating the pixels simultaneously which is in a single step so that entire processing speed of OIP is similar to light propagation speed which is higher than real time video frame rate (25 Frames Per Second (FPS)). But the real time application of DIP is only possible by reducing their input frame rate according to their processing speed.[14]

Hybrid Image Processor (HIP) is one of the high processing speed real time image processors which are nothing but replacement of DFT by OFT in DIP.[15] A survey of literature reveals that there is no work carried out on the comparison of the speed analysis among this three image processors in a nutshell form. Hence in this paper it is tried to compare and find out the suitable processor to produce the output with enhanced quality under real time processing. The real image processing of these three are compared. It is found that the HIP is highly applicable and more suitable for all types of real time image processing than the others.

## 2. RESULTS AND DISCUSSION

***Analysis of processing time and speed of DIP:*** In DIP,[16] the DFT algorithm forms the spectra $G(u,v)$, which are the Fourier transform of the object image $g(x,y)$. The filter section contains the complex valued transfer function $H(u,v)$. The complex amplitude of the signal from the filter is $G(u,v)H(u,v)$; IDFT algorithm forms the inverse transform of this function to produce the output image. The output image is then viewed using a real time digital display (LCD display).

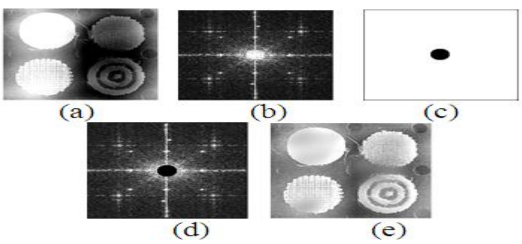


**Figure 1: (a) Image, (b) DFT spectrum, (c) Filter (band pass), (d) Filtered spectrum, (e) Filtered image.**

The simulated output obtained at each stage of DIP block for a given image (in $256 \times 256$ size),[17] is given in fig.1. The processing time and speed for the same are tabulated in Table 1.

**Table 1: Processing time and speed of each block in DIP.**

| **DIP sections** | **Processing time/frame in ms** | **Processing speed (Frames Per Second (FPS).** |
|---|---|---|
| Digital Camera | 40 | 25 |
| DFT | 78 | 12.8 |
| Filter spectrum- generation | 4 | 250 |
| Processing | 10 | 100 |
| IDFT | 62 | 16.1 |
| Digital Display- (LCD projector) | 40 | 25 |

***Analysis of processing time and speed of OIP:*** According to Scalar and Fraunhofer diffraction theories,[18] in the OIP setup, OFT lens (focal length of about 40cm) forms the spectra $G(u',v')$ in its back focal plane, which is the Fourier transform of object image $g(x,y)$. The spatial filter $H(u,v)$ placed at the back focal plane of the OFT lens and the spectra propagating away from the spatial filter is $G(u',v')H(u,v)$. The OIFT lens forms the inverse transform of this function to produce output image in its back focal plane. This processed image can be viewed or recorded through Digital Camera with display, which is kept at the back focal plane of the OIFT lens. The schematic diagram of OIP is given in fig.2.

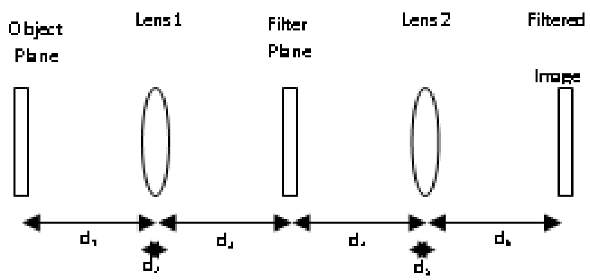


**Figure 2: Schematic diagram of OIP.**

Using the fig 2, the total time $T$ of the entire OIP for an image frame may be formulated by

$$T = \frac{1}{c}\left(d_1 + n_1 d_2 + d_3 + d_4 + n_2 d_5 + d_6\right) \ldots\ldots (1)$$

Where $c$ is the velocity of light in air ($3 \times 10^8 ms^{-1}$.) and, $n_1$ and $n_2$ are the refractive indices of OFT and OIFT lens respectively. If $d_1 = d_3 = d_4 = d_6 = d_a = 0.4m$, $d_2 = d_5 = d_b = 0.001m$

and $n_1 = n_2 = n = 1.5$, then the processing time and speed for each block in OIP, were evaluated and presented in Table 2.

**Table 2: Processing time and speed of OIP.**

| OIP sections | Processing time per frame (ns) | Processing speed (FPS). |
|---|---|---|
| OFT | 3.3 | $3 \times 10^8$ |
| Filtering | negligible | Infinity |
| OIFT | 3.3 | $3 \times 10^8$ |

***Motivations of HIP*:** From the Table 1, the DIP processing speed for a given frame ($\approx$6.5FPS) is evaluated from the total processing time ($\approx$154ms) shown in Table 3. Under this speed DIP is applicable to some real time ($\approx$170ms/frame) applications by reducing their input frame rate ($\approx$6 FPS). This speed lies approximately between 5FPS and 12FPS. It depends on the selection of an image to be processed, selection of computer and the selection of the software etc.[19] However the Field-Programmable Gate Array (FPGA) based digital camera is required to supply the input with suitable frame rate.[20]

**Table 3: Processing time and speed of DIP and OIP.**

| Processing sections | DIP | OIP |
|---|---|---|
| DFT | 78ms | 3.3ns |
| Filter spectrum- generation | 4ms | Negligible |
| Processing | 10ms | Negligible |
| IDFT | 62ms | 3.3ns |
| Total processing- time/frame | 154ms | 6.6ns |
| Processing speed-(number of frames/s) | 6.49 | $1.5 \times 10^8$ |

Using the Table 2 the entire processing time (Table 3) of OIP can be calculated . It is in the order of nanoseconds, and therefore the speed of OIP is in the order of $10^8$ FPS which is highly exceeds the real time video frame rate (25FPS) and also very much higher than the processing speed of DIP. Thus, it proves that OIP is highly suitable and applicable for real time image processing. However OIP has certain drawbacks also.[5] i) It requires certain manual operations to be performed during the filtering section. ii) It is highly difficult to perform spatial domain image processing techniques such as edge detection, and pixel extraction etc.

Combining the advantages of both DIP and OIP, a new image processing technique is developed in which DFT is replaced by OFT in DIP.[21] This replacement develops a new Hybrid Image Processing (HIP) suitable for real time image processing. This replacement of

DFT in DIP by OFT would not be much expensive and also it can cut processing time of DIP significantly.

***Analysis of processing time and speed of HIP:*** In HIP the concept of modification required for the replacement of DFT by OFT in DIP has been shown in figures 3(a) and 3(b). In DIP (figure 3a) the given image is converted to electrical and then spectra of the image are obtained by DFT. In HIP (figure 3b), the spectra of the given image are obtained by OFT lens which are then converted into electrical signal using a digital camera.

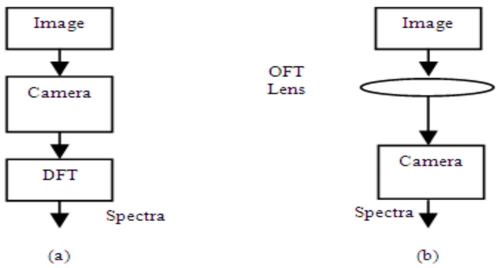


**Figure 3: (a) DFT in DIP (b) HIP (OFT in DIP)**

The processing time and speed of HIP (Table 4) can be evaluated from DIP and OIP (Table 3). From Table 4, the entire processing speed (≈13FPS) of HIP is (higher than DIP) still lower than real time input frame rate. If the high (double) speed computer [22] is used in HIP, it is enough to increase (double) the processing speed (≈26FPS) which is closer to the real time video frames rate. But the high (double) speed DIP (computer with dual processors-1GB RAM etc) has minimum processing time (≈78ms) and then it can be used for some real time applications with the maximum input frame rate (≈12FPS) which is still lower than real time video frame rate. So, FPGA digital camera is always required for DIP real time operations.[23] However some additional hardwares (Fig 4) are required in HIP for replacement of DFT by OFT.[24]

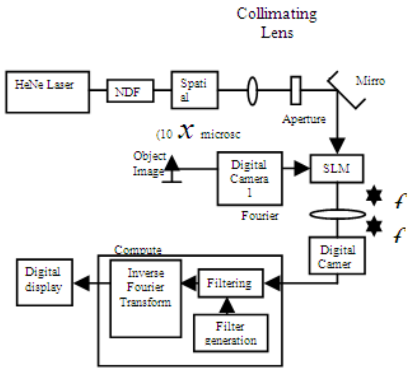


**Figure 4: Experimental setup of HIP.**

**Table 4: Processing time and speed of DIP, OIP and HIP.**

| **Processing sections** | **DIP** | **OIP** | **HIP** |
|---|---|---|---|
| DFT | 78ms | 3.3ns | 3.3ns |
| Filter spectrum- generation | 4ms | Negligible | 4ms |
| Processing | 10ms | Negligible | 10ms |
| IDFT | 62ms | 3.3ns | 62ms |
| Total processing time/frame | 154ms | 6.6ns | 76ms |
| Processing speed (number of frames/s) | 6.49 | $1.5\times10^{8}$ | 13.16 |

***Comparison of DIP, OIP and HIP***

Figure 5 shows the comparison of real time image processing of DIP, HIP1 (normal speed) and HIP2 (double speed). It is a graph between minimum real time/frame (fig2a) of DIP, HIP1 and HIP2 which are 157, 83 and 17 ms respectively versus the maximum frame rate for real time operation of DIP, HIP1 and HIP2 which are 6.5, 13 and 26 FPS respectively. The HIP2 ensures the high quality output because of its allowable input frame rate is closer to real time video frames rate.

**3. EXPERIMENTAL**

The simulation of DIP was performed using Pentium – IV with 256 MB RAM using MATLAB software. The processing time was carried out using MATLAB timer which is initiating at the beginning and stopping of it at the end of the block. Speed was evaluated from the processing time (Table 3).

In the experimental setup (Fig 4) of HIP (based on the OIP which is constructed at Department of Physics, Sri Sathya Sai Institute of Higher Learning (Deemed University), Prasanthi Nilayam, Andhra Pradesh, India) the digital camera 1 (Product Dimensions is 25 x 20 x 25 inches and Record & Display at 120 FPS) converts the object image $g(x,y)$ to electrical and then it is supplied to Spatial Light Modulator (SLM). Here the image ($1\,cm^2$) is illuminated by the collimated light beam obtained from the set of Helium-Neon LASER ($\lambda = 632.8nm$ and $P = 10mW$), Neutral Density Filter (NDF), Spatial Filter, Collimating Lens, an Aperture and mirror [figure 3] so that the information of the object image gets impressed on the beam after it passes through the SLM. The spectra $G(u',v')$ of the image obtained by OFT lens are converted to digital by real time camera 2. Then it is applied to the computer filtering section, which contains the complex valued filter transfer function $H(u,v)$. The complex amplitude of the output signal from the filter is $G(u',v')H(u,v)$; IDFT algorithm forms the inverse transform of this function to produce the output image. The output image is then viewed through a real time Digital display.

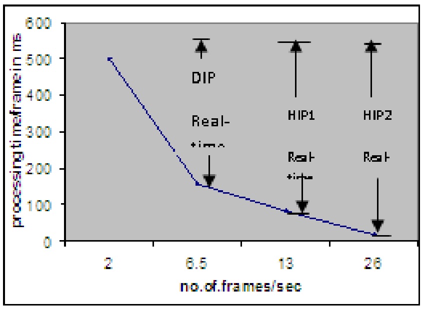


**Figure 5: Comparison of DIP and HIP.**

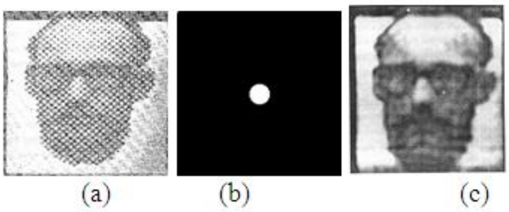


**Figure 6: (a) Image, (b) filter (low pass) (c) filtered image.**

The digital cameras in this system can only record the amplitude or intensity information.[25] The phase information needs to be recorded by the use of another reference wave front with interference technique. However the absence of inherent errors due to sampling, quantizing and aliasing process in OFT leads the quality of the output of HIP to get enhanced (fig 6). HIP has been further enhanced by the introduction of various recent advanced techniques.[17] like uni and multi-spectral imagery, beam pattern correction algorithm, edge detection algorithm and Teslation algorithm etc. as in DIP.

## 4. CONCLUSION

We have identified that the entire processing time/frame of OIP is in the order of nanoseconds whereas in DIP and HIP it is in the order of milliseconds. The conventional DIP is applicable to some real time applications only by reducing their input frame rate. From the comparison among OIP, DIP and HIP, HIP ensures the high quality output because of its allowable real time input frame rate**.**

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