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Original Research Paper

Engineering

DESIGNING A DIGITAL SIGNAL PROCESSOR BASED ON OPTICAL SIGNAL PROCESSOR WITH FEEDBACK: AMPLITUDE AND PHASE CONTROL

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ABSTRACT The development of real-time coherent optical signal processors has increased the appeal of optical computing techniques in signal processing applications. The application of suitable optical feedback techniques in real-time coherent optical signal processors employs to obtain simultaneous and independent amplitude and phase control of the signal passing through the system. In this paper, a digital signal processor with feedback has been designed and compared with an optical signal processor; both are employing simultaneous and independent amplitude and phase control. It is inferred that the quality of the output of digital signal processor with feedback is better than the digital signal processor without feedback and also closer to optical signal processor with feedback.

KEYWORDS : DIP, dual Magnitude and amplitude control, Feedback, HIP, OIP, Real-time processing,

1. INTRODUCTION

The development of real-time optical signal processors has stimulated interest in the coherent and incoherent optical processing of signals. Some of these real-time processors are commercially available such as GaAs-based multiple-quantum-well spatial light modulators [1], high-speed optical interconnects [2] and adaptive-array processor [3], etc.

These devices have the capability of processing large amounts of data in a relatively short time span due to their parallel processing ability [4]. However, there are some unusual constraints imposed on these real-time processors. They are essentially phase- only devices, and the optical material that applies information to the coherent light passing through the device imposed only phase modulation on the light.

When employing one of these devices, there is a choice of phase processing or amplitude processing of a signal. The choice depends on the specific situation in which the system is applied. We wish to use the processor as a spatial filter in the Fourier plane of some image. In general spatial filtering applications the phase control is more crucial than the amplitude control.

In recent years, considerable attention has been devoted to phase-only reconstruction and processing of signals; it is generally known that phase information is more useful than amplitude information in holographic image reconstruction [5]. Indeed, it is possible to obtain good image reconstruction by using only the phase of the image's Fourier transform. In fact, experimental evidence also indicates that it is not possible to obtain similar results through the use of the transform magnitude alone. The implication is that phase control is more crucial than amplitude control in general spatial filtering applications.

Based on the optical feedback system of Jablonowski and Lee [6], Gallgher [7] proposed three different schemes, all using optical feedback. These three are (1) phase-only forward filter and phase-only feedback filter, (2) phase only forward filter and magnitude only feedback filter and (3) magnitude-only forward filter and phase-only feedback filter. He analyzed and compared all these methods. He concluded that although all three approaches offer some magnitude and phase control, the greatest flexibility is obtained with the purely phase-only system of first scheme. This system allows an independent choice of magnitude and phase for the system transfer function. Keeping these facts in our mind, we have planned to design a new Digital Signal Processor based on the first method.

A survey of literature reveals that there is no work carried out on the designing and comparison of the performance analysis between these two image processors in a nutshell form. Hence in this paper, it is tried to compare and find out a suitable processor to produce the output with enhanced quality. The real image processing of these are compared. It is found that the DIP with feedback is highly applicable and more suitable for all types of still image processing.

2. Motivation of feedback systems

In optical signal processors [8], only one signal is recorded at any time on the recording material [9]. This precludes simultaneous independent amplitude and phase control over the light incident on the processing medium. In other words, we do not have the freedom to control independently both amplitude and phase of the light as it passes through the device [10]; therefore we assume that we may use either amplitude or phase processing on a signal, but not both simultaneously. In order to obtain both magnitude and phase control over light, it is necessary to use two optical devices or to somehow use the same device two different times, perhaps by implementing a feed-back loop through the device. Based on the same feedback systems, it is tried to design a DIP which provides both simultaneous and independent amplitude and phase control.

3. Optical signal processor with feedback system

A typical optical feedback system is depicted in Fig 1. The input signal to be filtered $s(x.y)$ is formed in plane P_1, and the filtered output $o(x.y)$ is formed in plane .P_3 The plane P_1 is the front focal plane of lens L_1. The mirror M_1 is pivoted at an angle of -θ rad from the plane P_1. Plane P_2 is both the back focal plane of lens and front focal plane of lens L_1. This plane contains two spatial filters L_2: the forward loop filter $H(u,v)$ and the feedback loop filter $G(u,v)$. The back focal plane of L_2 is P_3, and it contains a second mirror M_2 pivoted at an angle of θ rad from this plane.

This system with phase-only forward filter and phase-only feedback filter allows an independent choice of magnitude and phase for the system transfer function $T(u,v)$ The phase of $T(u,v)$ may be completely arbitrary from $-\pi$ to π, and although the allowable range on $|T(u,v)|$ is restricted, the value of $|T(u,v)|$ may be chosen anywhere within this range independently of the phase of $T(u,v)$. However OIP has certain drawbacks also [11]. i) It requires certain manual operations to be performed during the filtering section. ii) The position of the digital (CCD) camera is adjusted so as to get a sharp image of the object. iii) It is highly difficult to perform spatial domain image processing techniques such as edge detection, and pixel extraction etc. Hence, it is necessary to develop a DIP having both simultaneous and independent amplitude and phase control.

4. Digital signal processor with feedback system

In digital image processors [12,13], it is investigated a feedback loop that may be used to obtain dual magnitude and phase control. In order to accomplish this, we use the optical feed-back scheme of Gallgher [6]. A typical feedback system is depicted in Fig. 2 which is the modeling of Fig 1.

This system contains two spatial filters: the forward loop filter *H(u,v)* and the feedback loop filter *G(u,v)* The input signal to be filtered is *s(x,y)* and the filtered output is *o(x.y)*

A brief derivation of the system transfer function provides insight into the properties of this feedback system. First, we define few parameters. The input and output amplitude control coefficients are R_1 and R_2, respectively. The transmittance coefficients $T1$ and T_2 which are defined as $T_1 = 1 - R_1$ and $T_2 = 1 - R_2$.

The transform of the signal moving away from the summing block is given by the following expression:

$$T_1 S(u,v) + R_1 F(u,v) \qquad (1)$$

where *S(u,v)*. is the Fourier transform of the input signal *s(x,y)* and *F(u,v)*. is the transform of the feedback loop contribution. The signal moving away from forward loop filter *H(u,v)*. is then written as

$$H(u,v)[T_1 S(u,v) + R_1 F(u,v)] \qquad (2)$$

The signal entering into the IFFT$_{fw}$ block is given by the following equation 3.

$$O(u,v) = T_2 H(u,v)[T_1 S(u,v) + R_1 F(u,v)] \qquad (3)$$

It is necessary to determine *F(u,v)*in order to specify the function *O(u,v)*. The function describes the signal moving away from the feedback filter *G(u,v)*. Hence,

$$F(u,v) = \left[\frac{R_2}{T_2} O(u,v)\right] G(u,v) \qquad (4)$$

Combining Eqs. (3) and (4) produces

$$T(u,v) \equiv \frac{O(u,v)}{S(u,v)} = \frac{T_1 T_2 H(u,v)}{[1 - R_1 R_2 H(u,v) G(u,v)]} \qquad (5)$$

5. Digital feedback with Phase-only Filters

By phase-only forward and backward filtering, *H(u,v)* and *G(u,v)* may be written as

$$H(u,v) = \exp[i\,\psi(u,v)] \quad \text{and} \quad G(u,v) = \exp[i\,\gamma(u,v)] \qquad (6)$$

that is, the filters H and G impose only a phase shift on the signal passing through them. Substituting Eq.(6) in Eq.(5), we find

$$T(u,v) = \frac{T_1 T_2 \exp[i\,\psi(u,v)]}{1 - R_1 R_2 \exp[i\,\rho(u,v)]} \qquad (7)$$

where $\rho(u,v) = \psi(u,v) + \gamma(u,v)$ There is arbitrary freedom in choosing the phase functions $\psi(u,v)$ and $\rho(u,v)$ independently of one another from $\pi-$ to π; thus, we have the freedom to choose any desired phase for the transfer function *T(u,v)* through the choice of $\psi(u,v)$. The ability to choose $\rho(u,v)$ allows some flexibility in specifying the magnitude of *T(u,v)*. This is illustrated in Fig.3, which contains a plot of the denominator function of Eq.(7).

This function $1-R_1R_2\exp[i\rho(u,v)]$ may assume any value on the circle of radius R_1R_2 centered at the point 1 on the Re axis. Consequently, $|1-R_1R_2\exp[i\rho(u,v)]$ranges in value anywhere in $1-R_1R_2$, $1+R_1R_2$ So *T(u,v)* may range from $\frac{(1-R_1)(1-R_2)}{1+R_1R_2}$ to $\frac{(1-R_1)(1-R_2)}{1-R_1R_2}$.

It has already been stated that R_1 and R_2 have a range of (0,1); it is instructive to examine these limiting cases: $R_1R_2 \to 0$ and $R_1R_2 \to 1$. As in the first case $R_1R_2 \to 0$ the range of $[1/(1+R_1R_2), 1/(1-R_1R_2)]$ becomes $(\frac{1}{2}, \infty)$, although the maximum value of *T(u,v)*, $(1-R_1)(1-R_2)/(1-R_1R_2)$ becomes very small. As this limiting case is approached, we obtain a high dynamic range system with low gain. Physically speaking, the input and output amplitude control coefficients become totally resistive so that the output image intensity drops to zero.

In the second case $(R_1R_2 \to 0)$ the denominator of $|T(u,v)|$ assumes the constant value of 1 as does *T(u,v)* itself. All magnitude control on $|T(u,v)|$ is lost. In this case the input and output amplitude control coefficients transmit the entire signal incident on them, and the feedback loop becomes nonexistent.

Typically there is a minimum acceptable average value for $|T(u,v)|$, and this value will determine the maximum of R_1 and R_2. The final result is that it is possible to achieve independently both arbitrary phase and limited magnitude control for a spatial filter, utilizing phase-only filters and digital feedback system.

6. Experimental

The experimental outputs obtained from DIP with feedback are shown in Fig.4 [amplitude ($R_1 = R_2 = 0.1$) control only], Fig.5 [phase control(both forward and feedback filters phase angles are -1 radians) only] and Fig.6 (simultaneous and independent Phase and amplitude control):. Further, it is compared with the experimental output of OIP with feedback [14] which is shown in Fig.7..

7. CONCLUSION

In this work, DIP with feedback has been designed following the Gallgher proposed method on OIP. In DIP system the input and output amplitude control coefficients, R1 and R2 do the same role of mirrors M1 and M2 as OIP with feedback. Further, the phase control of the above system is achieved by both forward and feedback phase only filters which is similar to the role of forward and feedback optical filters at plane P2 in OIP with feedback. It is surprisingly to note that both the independent and simultaneous amplitude and phase control in DIP have been achieved. It is found that the quality of the output of DIP with feedback is better than DIP without feedback and also closer to OIP with feedback.

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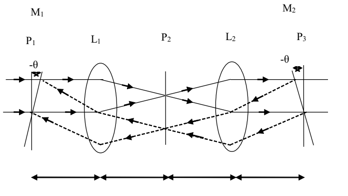


Figure 1. Optical signal processor with feedback system

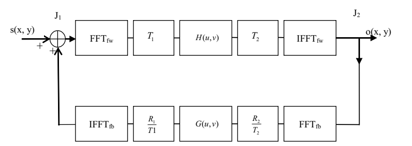


Figure 2. Digital signal processor with feedback system

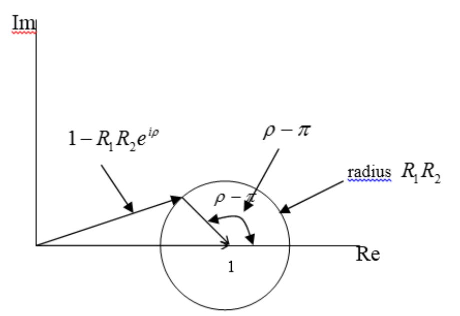


Figure.3. Denominator function 1-*R*1*R*2 exp $(i\rho)$

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

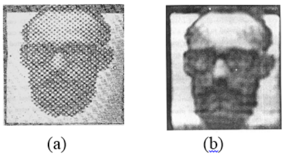
Figure 4… Output of DIP with feedback (Amplitude control only): (a) input image; (b) first output (without feedback); (c) second output; (d) third output; (e) fourth output

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

Figure 5… Output of DIP with feedback (Phase control only): (a) input image; (b) first output (without feedback); (c) second output; (d) third output; (e) fourth output

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

Figure 6 Output of DIP with feedback (Simultaneous and independent Phase and Amplitude control): (a) input image; (b) first output (without feedback); (c) second output; (d) third output; (e) fourth output



(a) (b)

Figure 7… Output of OIP with feedback: (a) input image; (b) output image

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