NAIC-ID(RS)T-040494

NATIONAL AIR INTELLIGENCE CENTER

STUDY OF LIQUID CRYSTAL SPATIAL LIGHT MODULATOR APPLICATION TO HADAMARD TRANSFORM SPECTROMETER -- A FAST AND ACCURATE DECODING METHOD

by

B. Zhang, Bingquan and Bi, Fengfei

NAIC-ID(RS)T-040494

NAIC-

HUMAN TRANSLATION

NAIC-ID(RS)T-0404-94 27 March 1995

MICROFICHE NR: 95C000104L

Study of Liquid Crystal Spatial Light Modulator Application to Hadamard Transform Spectrometer -- A Fast and Accurate Decoding Method

By: B. Zhang, Bingquan and Bi, Fengfei

English pages: 7

Source: Guangxue Xuebao, VOL 12, NR 7, July 1992

Country of origin: CHINA
This document is a Human translation.
Translated by: Scitran Company
Merged by: Nancy L. Burns
Requester: NAIC/TATA/J. Finley
Approved for public release; Distribution unlimited.

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE NATIONAL AIR INTELLIGENCE CENTER.	PREPARED BY: TRANSLATION SERVICES NATIONAL AIR INTELLIGENCE CENTER WPAFB, OHIO

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

TABLE OF CONTENTS

STUDY OF LIQUID CRYSTAL SPATIAL LIGHT MODULATOR APPLICATION TO HADAMARD TRANSFORM SPECTROMETER -- A FAST AND ACCURATE DECODING METHOD[1]

ZHANG, BINGQUAN and BI, FENGFEI[2]

Abstract

A study is made on liquid crystal spatial light modulator (LC-SLM), used as a stationary encoding mask of Hadamard transform spectrometer (HTS), and thus a fast and accurate decoding method is proposed; the improvement is given in terms of root-mean-square of the signal-to-noise ratio produced by the LC-SLM mask.

Keywords Liquid crystal spatial light modulator (LC-SLM), encoding mask, Hadamard transform spectrometer (HTS), the decoding method

1. Introduction

Hadamard transform spectrometer (HTS) was developed at the end of '60 and it is a kind of the Fourier transformation spectrometer which is a parallel multi-channel transmitting modulating spectrometer, and Harwit, Decker, and Sloane, et al. contributed a lot of work in this area [1-6]. In this spectrometer, an encoding mask is used to replace the incident aperture or the emission aperture in a conventional spectrometer. Usually a mechanical mask is being used as the encoding mask of the Hadamard transform light spectrometer, but because a

1 Date of Receipt: March 14, 1991; Date of receipt the revised version: June 11, 1991.

2 Laser Research Institute of Sushou University, Sushou 215006.

mechanic mask not only is slow in its scanning speed, but it has a rather large mechanic error, and thus it can only be applied in the region of molecular spectrometrical analyses. However, Tilotta, et al. [7] in 1987 started to use liquid crystal spatial light modulator (LC-SLM) to build an encoding mask and to design a Hadamard transform spectrometer of the stationary encoding mask which would thus provide future optical spectrometry with a spectrometer without "moving parts". By utilizing its measurable quantities of visible spectra, near infra-red spectra and visible Raman spectra, a huge success has been scored [7,8]. In 1989 Bohlke, et al. [9], remodified it for the use in near infra-red Raman spectra measurements and thus openned up a new way of observing the near infra-red Raman spectra. This paper starts out with the error-theory to propose a fast and accurate decoding method when LC-SLM is used to build the encoding mask, and thus established a relationship between the improving of the r.m.s. of signal-to-noise ratio and the switch characteristics of the LC-SLM encoding mask.

2. A fast and accurate encoding method

If n is the number of the established encoding units for the existing n spectral components which are to be observed, by use of n pieces of masks to carry out n times of measurements, the error in the ith measurement is e_i, and now suppose [6]: (1) e_i is not reliable in detecting the frivolous variable of the optical intensity; (2) The expectation value of e_i is zero; (3) Errors in all the individual measurement are mutually independent; (4) The mean square deviation of e_i is σ^2. Then

$$E\{e_i\}=0,\quad E\{e_i\cdot e_j\}=0,\quad E\{e_i^2\}=\sigma^2. \qquad (1)$$
$$i,\ j=1,\ 2,\ \cdots,\ n \quad i\neq j$$

where E shows the expectation value or the average value of a large amount of experiments. Based on the previous suppositions for errors, one can obtain the following expression for errors e_i, e_2,..., e_n of the n times of measurements when n is large:

$$\frac{1}{n}\sum_{i=1}^{n} e_i=0. \qquad (2)$$

as it is shown in Reference [7], the spectral response in the visible spectral region of (350 nm - 800 nm) turns out to be stable due to the switch characteristics of LC-SLM, after its liquid crystal display-device of the twisted columnar phase of AND Co. Model 12A type was modified to show such LC-SLM switch characteristics. The average value of transparency is 32 % during light is shone through, the average value of transparency is 1.5 % when it is opaque. It is clear from Reference [9] that when PDLC (polymer chromatic dispersion liquid crystal) is used as the LC-SLM, the switch characteristics around infra-red spectral region (10,000 cm^{-1} - 5,500 cm^{-1}) is also quite stable. When light is shone through, the transparency hovers within 78 % - 81 %, while when it is opaque, the transparency rate varies in 2% - 11%. Based on the above facts, although one can assume the switch characteristics of LC-SLM in a certain optical spectral range to be constant, yet for different spectral regions the constants may turn to be all different.

If T_h is the transparency when a liquid crystal mask encoding unit is shone through by a optical beam and T_o is the transparency when it is not being shone, the open or close operations of a mask encoding unit is carried out by each row of matrix-elements of matrix-column S_n of the left-turning S ring of the Mth column structure; that is, if the corresponding matrix-element is "1", the corresponding encoding unit of the mask is allowing the light through; while the corresponding unit is "0", the corresponding encoding unit of the mask is opaque. Thus by letting the matrix-element 1 of S_n changes to T_h or letting matrix-element 0 changes to T_o, one can get the actual encoding matrix S_n' of the mask and thus S_n' can be shown by

$$S'_n = T_h S_n + T_0 (J_n - S_n) = (T_h - T_0) S_n + T_0 J_n, \tag{3}$$

where J_n is for all the matrix-elements to be 1 in the n-step equation, but for the property of the S-matrix and characteristics of S-matrix of the Mth columnar structure, one may refer to Ref.[6]. The energy applied to the encoding units of the mask is shown by vector ψ, this ψ is the intensity vector of the actual optical spectral component which can be shown by vector η, namely

$$\eta = S'_n \psi + e. \tag{4}$$

Now according to S_n which was used as the encoding matrix of the mask, one can carry out decoding with the same decoding method, and by use of Eqn.(3) and Eqn.(4) one gets the actual estimated spectral value (the first step) $\hat{\psi}$ to be

$$\hat{\psi} = S_n^{-1} \eta = (T_h - T_0) \psi + \frac{2T_0}{n+1} \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix} \sum_{i=1}^{n} \psi_i + S_n^{-1} e, \tag{5}$$

By summing up the components of the vector quantities at both sides of Eqn.(5), one gets

$$\sum_{i=1}^{n} (\hat{\psi})_i = \sum_{i=1}^{n} [(T_h - T_0)\psi]_i + \sum_{i=1}^{n} \left\{ \frac{2T_0}{n+1} \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix} \sum_{j=1}^{n} \psi_j \right\}_i + \sum_{i=1}^{n} (S_n^{-1} e)_i. \tag{6}$$

Now one computes each individual terms of Eqn.(6) to get

$$
\left.
\begin{aligned}
&\sum_{i=1}^{n} (\hat{\psi})_i = \sum_{i=1}^{n} \hat{\psi}_i, \\
&\sum_{i=1}^{n} [(T_h - T_0)\psi]_i = (T_h - T_0) \sum_{i=1}^{n} \psi_i, \\
&\sum_{i=1}^{n} \left\{ \frac{2T_0}{n+1} \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix} \sum_{j=1}^{n} \psi_j \right\}_i = \frac{2T_0 n}{n+1} \sum_{i=1}^{n} \psi_i, \\
&\sum_{i=1}^{n} (S_n^{-1} e)_i = \frac{2}{n+1} \sum_{i=1}^{n} [(2S_n - J_n)e]_i = \frac{2}{n+1} \left[\sum_{i=1}^{n} (2S_n e)_i - \sum_{i=1}^{n} (J_n e)_i \right] \\
&\qquad = \frac{2n}{n+1} \cdot \frac{1}{n} \sum_{i=1}^{n} e_i = 0.
\end{aligned}
\right\} \tag{7}
$$

In substituting Eqn.(7) into Eqn.(6), one gets

$$
\sum_{i=1}^{n} \psi_i = \frac{n+1}{(n+1)T_h + (n-1)T_0} \sum_{i=1}^{n} \hat{\psi}_i, \tag{8}
$$

$$
\hat{\psi} = (T_h - T_0)\psi + \frac{2T_0}{(n+1)T_h + (n-1)T_0} \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix} \sum_{i=1}^{n} \hat{\psi}_i + S_n^{-1} e, \tag{9}
$$

namely

$$
\frac{1}{T_h - T_0} \left(\hat{\psi} - \frac{2T_0}{(n+1)T_h + (n-1)T_0} \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix} \sum_{i=1}^{n} \hat{\psi}_i \right) = \psi + \frac{1}{T_h - T_0} S_n^{-1} e. \tag{10}
$$

Now the corrected estimated spectral value can be shown by $\hat{\psi}_{\mathrm{MOD1}}$ as follows : if

$$
\hat{\psi}_{\mathrm{MOD1}} = \frac{1}{T_h - T_0} \left(\hat{\psi} - \frac{2T_0}{(n+1)T_h + (n-1)T_0} \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix} \sum_{i=1}^{n} \hat{\psi}_i \right), \tag{11}
$$

then

$$
\hat{\psi}_{\mathrm{MOD1}} = \psi + \frac{1}{T_h - T_0} S_n^{-1} e. \tag{12}
$$

Here the average mean square deviation ε is as follows:

$$
\varepsilon = \frac{1}{n} \sum_{i=1}^{n} \varepsilon_i = \left(\frac{1}{T_h - T_0} \right)^2 \varepsilon_{\text{[illegible]}}. \tag{13}
$$

From Ref.[6],

$$
\varepsilon = \varepsilon_i = \frac{4}{n} \left(\frac{1}{T_h - T_0} \right)^2 \sigma^2. \tag{14}
$$

The increment $\Delta(\mathrm{SNR})_{r.m.s.}$ of the room mean square signal-to-noise ratio is

$$\Delta(SNR)_{\mathrm{r.m.s.}} = \left[\frac{E\{(\hat{\psi}_i - \psi_i)^2\}_{\text{没有多路传输}}}{E\{[(\hat{\psi}_{\mathrm{MODI}})_i - \psi_i]^2\}_{\text{有多路传输}}}\right]^{1/2} = \frac{\sqrt{n}}{2}(T_h - T_0). \tag{15}$$

Now if $T_h = 1$ and $T_o = 0$, then Eqn.(12), Eqn.(13) and Eqn.(15) yield $\hat{\psi}_{\mathrm{MODI}}$、$\varepsilon$、$\varepsilon_i$ and $\Delta(SNR)_{\mathrm{r.m.s.}}$, which totally agree with $\hat{\psi}$、ε、ε_i and $\Delta(\mathrm{SNR})_{r.m.s.}$ of the corresponding standard encoding mask of encoding matrix S_n.

3. Conclusion

1) When one uses LC-SLM to build an encoding mask, still one should first carry out the fast-speed Hadamard transformation to the measured vector η according to the standard encoding mask, to obtain the estimated spectral vector value (the first step) $\hat{\psi} = S_n^{-1}\eta$, , but for the actual computation, one may refer to Ref.[10]. Afterwards one should carry out some modification on the estimated value ψ, to obtain the revised estimated spectral value $\hat{\psi}_{\mathrm{MODI}}$, of Eqn.(11), and thus $\hat{\psi}_{\mathrm{MODI}}$ is none other than the best estimated value of the actual spectrum.

2) Based on the decoding method presented by us, by use of LC-SLM as the HTS encoding mask we could work out the room mean square increment of the signal-to-noise ratio $\Delta(SNR)_{\mathrm{r.m.s.}} = (\sqrt{n}/2)(T_h - T_0)$, to see the drop in $\Delta(\mathrm{SNR})_{r.m.s.}$ by comparing with the standard encoding mask.

3) By use of Eqn.(3) and Eqn.(11), the present authors worked out a computer simulation to prove that the presented decoding method is accurate.

References

[1] N. J. A. Sloane *et al.*, *Appl. Opt.*, 1969, **8** (10): 2103

[2] J. A. Decker *Jr. et al.*, *Appl. Opt.*, 1969, **8** (12): 2552

[3] P. G. Phillips, M. Harwit., *Appl. Opt.*, 1971, **10** (12): 2780

[4] M. Harwit, *Appl. Opt.*, 1971, **10** (8): 1415

[5] M. Harwit, *Appl. Opt.*, 1973, **12** (2): 285

[6] M. Harwit, N. J. A. Sloane, *Hahamard Transform Optics*. New York: Academic Press., 1979

[7] D. C. Tilotta *et al.*, *Appl. Spectrosc.*, 1987, **41** (5): 727

[8] D. C. Tilotta *et al.*, *Appl. Spectrosc.*, 1987, **41** (8): 1280

[9] A. P. Bohlke *et al.*, *J. Mol. Structure* (*Thechem*), 1989, **200**: 471~481

[10] 张炳泉. *光学学报*, 1984, **4** (3): 229

DISTRIBUTION LIST

DISTRIBUTION DIRECT TO RECIPIENT

ORGANIZATION	MICROFICHE
B085 DIA/RTS-2FI	1
C509 BALLOC509 BALLISTIC RES LAB	1
C510 R&T LABS/AVEADCOM	1
C513 ARRADCOM	1
C535 AVRADCOM/TSARCOM	1
C539 TRASANA	1
Q592 FSTC	4
Q619 MSIC REDSTONE	1
Q008 NTIC	1
Q043 AFMIC-IS	1
E051 HQ USAF/INET	1
E404 AEDC/DOF	1
E408 AFWL	1
E410 AFDTC/IN	1
E429 SD/IND	1
P005 DOE/ISA/DDI	1
P050 CIA/OCR/ADD/SD	2
1051 AFIT/LDE	1
PO90 NSA/CDB	1
2206 FSL	1

Microfiche Nbr: FTD95C000104L
NAIC-ID(RS)T-0404-94