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To cite this article: Jin Yi *et al* 2005 *Phys. Scr.* **2005** 98

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Ternary Optical Computer Architecture

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Received October 18, 2003; revised version received July 27, 2004; accepted August 13, 2004

PACS number: 42.79.Ta

Abstract

A fire-new way to construct an optical computer is put forward in this paper. Distinguished from others, the optical computer in this study expresses information by two polarized states with orthogonal vibration directions and no-intensity of light, therefore it was named ternary optical computer. Constituting its general architecture by the good combination of electric control and optical calculation, the ternary optical computer employs optical fiber ring as register, semiconductor memory as ternary cell, and liquid crystal as modulator and adder. Meanwhile, an electronic computer group produces signals to control every part of the ternary optical computer. The superiority of this novel ternary optical computer was also introduced in this paper.

1. Introduction

With the progress made in electronic computers, liquid crystals and optical fiber communication, it is well-time to develop the optical computer. Compared with electronic computers, much more digits and no radio attenuation are native and peculiar in optical computers. These two characteristics attracted many scientists to devote themselves to optical computer research. As a result a few optical computers, either comprising electricity operation and light connection or based on symbolic substitution [1, 2], have emerged in the world. It is worth to point out that binary code representation was adopted in these optical computers. In this paper, the basic architecture of a new optical computer, ternary optical computer (TOC), is put forward.

2. Principle of the ternary optical computer

The polarization direction of light can be used to express information. For instance, horizontal polarization was selected to represent information 0 and vertical polarization to express information 1 in some optical operations [3]. In our TOC, two perpendicular polarization directions and no light state are selected to represent the ternary optical signals. Here, horizontal polarization represents information 2, vertical polarization 1 and no light 0 [4].

In the TOC, ternary code 0, 1 and 2 can be changed into corresponding ternary optical signals via a modulator as shown in Fig. 1, and the inverse transform can be accomplished by the demodulator shown in Fig. 2. Meanwhile, the information will steadily transmit in original state from one part to another through space or fibers inside an optical computer because the polarizing direction keeps invariable when light passes through homogeneous medium.

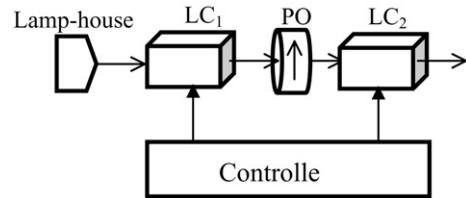


Fig. 1. Light Modulator Structure.

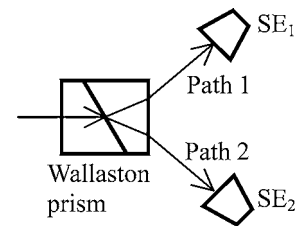


Fig. 2. Light Demodulator.

3. Modulator and demodulator

The modulator comprises a pair of liquid crystals (LC_1 and LC_2) and one polarimeter (PO), as schematically shown in Fig. 1. The liquid crystals cause the polarization direction of the transmission light to turn 90° provided that a controlling voltage is applied. Assume the lamp-house emits vertical polarization light that can pass the polarimeter, a vertical polarization light pulse, expressing information 1, is sent from the modulator when no voltage is pressed on LC_1 and LC_2 . Applying the controlling voltage on LC_2 , a horizontal polarization light pulse representing information 2 is sent, and on LC_1 , no light is sent.

The demodulator contains a Wallaston prism and two sensitive elements (SE_1 and SE_2), as shown in Fig. 2. When a light pulse arrives at the receiver, the vertical polarization light will go along the path 1 and illuminate the SE_1 , and the horizontal polarization light will go along path 2 and illuminate the SE_2 . That is to say, an output from SE_1 indicates the reception of the information 1 while an output from the SE_2 means the reception of the information 2. If nothing comes out from the SEs, the information 0 is received.

4. Ternary adder

Fig. 3 schematically illustrates the ternary adder structure which contains four liquid crystals (LC_1 , LC_2 , LC_3 and LC_4), two optical switches (k_1 and k_2), four horizontal polarimeters (h_1 , h_2 , h_3 and h_4), and three vertical polarimeters (v_1 , v_2 and v_3). The adder can complete ternary arithmetic, which add a and b and simultaneously export d on the original digit place and the carry digit c . See table I.

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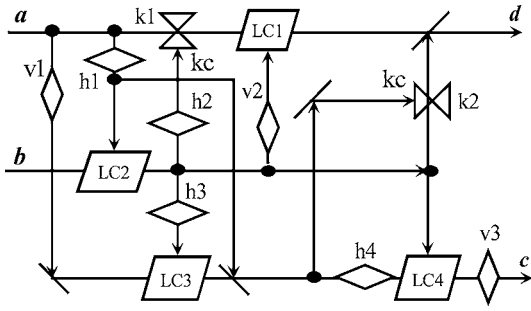


Fig. 3. Schematic diagram of adder structure.

Table I. Logical of a , b , d , and c .

a	b	d	c
0	0	0	0
0	1	1	0
0	2	2	0
1	0	1	0
1	1	2	0
1	2	0	1
2	0	2	0
2	1	0	1
2	2	1	1

The optical switches can be made of liquid crystals and polarimeters or be produced in other ways [5]. In the case of a control signal entering the point kc of the switches, the optical switches will turn off to prevent any light from passing through. On the contrary, the switches will turn on permitting light to pass through.

The horizontal polarimeters allow horizontal polarization light passing and the vertical polarimeters allow vertical polarization light passing.

At receiving a control signal, the liquid crystals will cause the polarization direction of the transmission light to turn 90 degrees.

The detailed operation of a ternary adder is interpreted as follows.

Firstly, when the ternary code in digit place a is zero, i.e. $a = 0$, light in b can overpass LC2 and k2. Therefore, we have $d = b$ (0, 1, 2) and $c = 0$. Correspondingly, when $b = 0$, light in a can overpass k1 and LC1 but not h4, LC4 and v3. Here, we have $d = a$ (0, 1, 2) and $c = 0$.

Next, when $a = 1$, the vertical polarization light in a goes along v1 and LC3, giving a control signal to k2. As a result, k2 turns off, closing up the access to d for light in b . Under the circumstances that $b = 1$, the vertical polarization light in b can pass through v2 and send a control signal to LC1, leading the transit lights to change their polarization directions. Hence, the light in a will change into horizontal polarization after it passes through LC1, indicating that the ternary code becomes 2 in a , whereupon the output $d = 2$ is obtained. Meanwhile, owing to the vertical polarization, light in a can not overpass the horizontal polarimeter h4, the carry digit place receives no light signal resulting in $c = 0$. If $b = 2$, both switches k1 and k2 receive control signals and are closed, making the light in either a or b unable to reach d , i.e. $d = 0$. At the same time, LC3 and LC4, receiving control signals sent from b , cause the polarization light in a to change its direction twice and revert to original vertical. Therefore, the carry digit $c = 1$ is obtained when $a = 1$ and $b = 2$.

Lastly, when $a = 2$, the horizontal polarization light in a overpasses h1 sending a control signal to LC2, and simultaneously gives the k2 a signal too. Similar to the condition $a = 1$, the light in b is unable to reach d . Moreover, LC2 will make the polarization lights in b turn their directions 90 degrees. Here, if the ternary code in b is zero, i.e. $b = 0$, because the horizontal polarization light in a is able to arrive at d but not c , the result $d = a = 2$ and $c = 0$ is achieved. While if the code in b is nonzero, the LC4 will receive a control signal, and hence change the polarization light in a from horizontal to vertical after it passes through h1 and h4. As a result, the light in a goes through v3 continuously and reaches c . It is clear that the carry digit $c = 1$ will always be obtained when $a = 2$ and $b = 1$ or 2. Furthermore, if $b = 1$, the polarization light in b will change into horizontal after passing through LC2 and thereafter overpass h2 leading the switch k1 to turn off, which prohibits the light in a to transit. Thus $d = 0$. If $b = 2$, the light in b can go along v2 after being veered by LC2, giving LC1 a control signal. Then, the polarization light in a will turn to vertical after it transits the LC1, indicating $a = 1$. Consequently, the output is $d = a = 1$.

Summarizing the interpretation above we get Tab1, the ternary logicals list of a , b , d , and c .

5. Ternary adder unit

On the basis of the above ternary adders, a ternary adder unit can be build. As illustrated in Fig. 4, the ternary adder unit, adopting the adders shown in Fig. 3 as essential elements, contains m bundles of three-state light. A_i ($i = 0, 1, \dots, m$) denotes the ternary adder shown in Fig. 3, B_i represents the expansion part objective to complete adding $ci-1$ to di with no carry digit, and the part C_i aims to accomplish the addition of carry units. ei is the output of the No. i adder unit. When $ci-1 = 0$, di shoots out from ei via optical switch $ki2$, so $ei = di + (ci-1) = di$. When $ci-1 = 1$, the signal in $ci-1$ shoots out from ei via $ki1$ and LCi1, and simultaneously turns $ki2$ off preventing di from passing. In this instance, if $di = 0$, $ei = ci-1 = 1$; if $di = 1$, because the light in $ci-1$ will turn to horizontal polarization at leaving LCi1, thus $ei = 2$ is obtained; and if $di = 2$, $ki1$ is turned off, hence neither di nor $ci-1$ arrives ei , meaning $ei = 0$. However, when $di = 2$, it

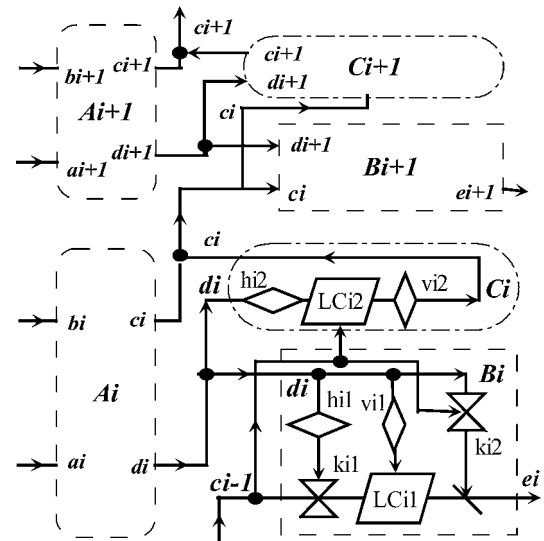


Fig. 4. Schematic diagram of ternary adder unit structure.

shoots out from ci via hi_2 , LCi_2 and vi_2 and puts number 1 to ci , i.e. $ci = 1$. In this way, the Bi and Ci cooperate to complete the accumulation of $(ci-1)$ and di .

The work cycle of the ternary adder unit can be divided into three steps. In the first step a series of Ai ($i = 1, 2, \dots, m$) completes the addition of ai and bi . In the case of $di = 2$ and $(ci-1) = 1$, Ci groups carry out the second step, accumulating $(ci-1)$ and di . Otherwise, Bi groups complete the third step, which is adding di and $(ci-1)$ and exporting ei as the result. The first and last steps cost constant time, nevertheless the period of the second step will depend on the maximum numbers of successive Ai , all of which have the output $di = 2$.

Considering the liquid crystal display technology, the ternary adder unit will contain over a million digits, say $m > 10^6$. This means that a manager for m bundles of three-state light needs to be created in future computer operation system.

6. Memory technique

An optical fiber ring, being used in optical fiber communication, can be adopted as register in the information operation unit of the TOC for storing three-state optical signals. Keeping the light in itself for over 30 minutes, the optical fiber ring is suitable as information operation unit.

Two bits of semiconductor memory can be used to store one ternary digit via storing the control signals of LC_1 and LC_2 (Fig. 1) for the data to be operated. In the same way, we can store the signals exported from SE_1 and SE_2 (Fig. 2) for the data having been operated. It is the ternary cell that can be built from semiconductor memory chips. Due to the cheapness of the semiconductor chip, the methods will be economically efficient to build the TOC data memory.

7. Basic architecture of TOC

The basic architecture of the TOC can be divided into three parts, optical operation unit (OOU), data version unit (DVU) and electric control unit (ECU), as shown in Fig. 5. The optical operation unit consists of optical data bus, optical fiber ring, optical path choice element, optical operation element, optical input/output

equipments and four optical switches. The ternary data with a mass of digits are dealt with in the OOU in the form of three-state optical signals at the same time. The electric control unit consists of electric bus, control CPU group, program memory, data memory and I/O devices. Being an electronic computer system in fact, the ECU sends control signals to every part of the TOC but keeps the data unhandled. The CPU group of ECU runs the program having been stored in the program memory and exports the control signals. Meanwhile the data are sent into the OOU from the data memory via the processing of the DVU. The data version unit consists of data changer, ternary data memory, modulator and demodulator. The data changer transforms the data from binary system to ternary system, or the reverse. The ternary data memory is made of semiconductor chips and used to store the ternary code data, either control signals to LC_1 and LC_2 in the modulator or output signals of SE_1 and SE_2 in the demodulator. The modulator transforms the electric signals in the ternary data memory into three-state optical signals and further loads them to the optical data bus. As for the demodulator, the case is the contrary. The optical input/output equipments are ternary optical signal devices, for example a ternary optical fiber communication dispatcher and receiver [6]. The I/O devices are electric computer I/O equipments taken in use recently.

Because the program runs in the electron digit computer group, it is inferred that the popular software can sequentially find its way in the future. Clearly, the TOC is able to utilize the up to date computer technology as much as possible in software as well as in hardware.

8. Conclusion

In a word, an optical computer can be built with liquid crystal, polarimeter, optical fiber ring, semiconductor memory and electronic computer. The information can be expressed and calculated via two orthogonal polarized states and no-intensity of light.

Despite requiring more semiconductor memories for ternary data storage in TOC, great benefits can be achieved due to the high performance of TOC and the low cost of semiconductor memory chips. Similarly for data processing, although the ternary adder employs more liquid crystal elements than the binary adder of the same type, TOC is superior in performance-price ratio to binary optical computer owing to the cheap liquid crystal elements and the mature integrated manufacture technique.

According to the TOC architecture described above, at present, the processing data rate (PDR) of TOC is temporarily limited by the speed of electron computer and electrical element. However, the strong parallel processing capability, i.e. dealing with no less than 10^6 digit positions simultaneously, makes the TOC easily exceed the present best giant electron computer in data processing. Meanwhile, attributing to numerous parallel processing digit positions and no radiation attenuation of light, the data transmission rate of TOC is much higher than that of giant electron computers.

Looking forward, progress in optical computer inevitably urges the development of optical elements, which in turn helps the optical computer to gradually break through the PDR limitation caused by electron computer and electrical element. Nevertheless, it is unreasonable to cast aside electrical elements altogether, because perfect performance-price ratio of optical computer can be gained by employing electrical elements as much as possible due to their availability and cheapness.

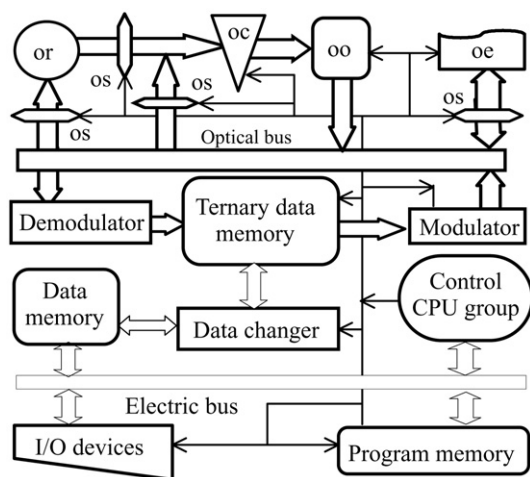


Fig. 5. Schematic diagram of TOC basic structure, or: optical fiber ring, os: optical switch, oc: optical path choice element, oo: optical operation element, oe: optical input/output equipment.

Apparently, the optical computer is suitable for occasions requiring considerable computation, such as weather forecast, earthquake prediction, complex graphics and image manipulation, huge database searches, breaking ciphers, and so on.

Acknowledgement

The research was supported by the National Natural Science Foundation of China under the Grant No. 60473008. The authors also appreciate Northwestern Polytechnical University for providing financial support via the Doctorate Foundation.

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