
Ternary Optical Computer Architecture

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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.

3. Modulator and demodulator

The modulator comprises a pair of liquid crystals (LC1 and LC2) 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 LC1 and LC2. Applying the controlling voltage on LC2, a horizontal polarization light pulse representing information 2 is sent, and on LC1, no light is sent.

The demodulator contains a Wallaston prism and two sensitive elements (SE1 and SE2), 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 SE1, and the horizontal polarization light will go along path 2 and illuminate the SE2. That is to say, an output from SE1 indicates the reception of the information 1 while an output from the SE2 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 (LC1, LC2, LC3 and LC4), two optical switches (k1 and k2), four horizontal polarimeters (h1, h2, h3 and h4), and three vertical polarimeters (v1, v2 and v3). 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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The optical switches can be made of liquid crystals and polarizers 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 directions 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, whereas the output \( d = 2 \) is obtained. Meanwhile, owing to the vertical polarization, light in a can not overpass the horizontal polarimeter k4, 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 vored 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 Table 1, the ternary logicals list of a, b, d, and c.

### Table 1. Logical of a, b, d, and c.

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<th>a</th>
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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. \( A_i(0, 1, 2) \) denotes the ternary adder shown in Fig. 3. \( B_i \) represents the expansion part objective to complete adding \( e_i \) to \( d_i \) with no carry digit, and the part \( C_i \) aims to accomplish the addition of carry units. \( e_i \) is the output of the No. i adder unit. When \( e_i = 0 \), \( d_i \) shoots out from \( e_i \) via optical switch k2, so \( e_i = d_i + (e_i-1) = d_i \). When \( e_i = 1 \), the signal in \( e_i \) shoots out from \( e_i \) via k1 and LC1, and simultaneously turns k2 off preventing \( d_i \) from passing. In this instance, if \( d_i = 0 \), \( e_i = e_i-1 = 1 \); if \( d_i = 1 \), because the light in \( e_i \) will turn to horizontal polarization at leaving LC1, thus \( e_i = 2 \) is obtained; and if \( d_i = 2 \), k1 is turned off, hence neither \( d_i \) nor \( e_i \) arrives \( e_i \), meaning \( e_i = 0 \). However, when \( d_i = 2 \), it

![Fig. 3. Schematic diagram of adder structure.](image1)

![Fig. 4. Schematic diagram of ternary adder unit structure.](image2)

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An optical fiber ring, being used in optical fiber communication,
ternary digit via storing the control signals of LC1 and LC2
information operation unit.
the TOC for storing three-state optical signals. Keeping the light
can be adopted as register in the information operation unit of
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 LC1 and LC2
(Fig. 1) for the data to be operated. In the same way, we can
store the signals exported from SE1 and SE2 (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,
output 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 LC1 and LC2 in
the modulator or output signals of SE1 and SE2 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 electronic 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.
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.

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