A Survey of Ternary Optical Computer Research

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***Abstract*—TOC, as a new type of computer, uses the state of light: it uses the non light state and two polarized light states with orthogonal polarization directions to represent information, and uses a rotator and polarizer to change the three light states, thus completing ternary logic operations. This new type of computer has the advantages of numerous processor bits, independent use of processor bits in groups, and reconfigurable computing functions of processor bits; After more than 20 years of development, we have achieved fruitful results. In this paper, the research progress of ternary optical computer is comprehensively and thoroughly analyzed and summarized, from the concept of TOC theory to the kilobit processor being studied so far. Firstly, the theory of ternary optical computer is summarized. Secondly, according to the core theory of ternary optical computer and the achievements that have been made, ternary optical computer has also made some progress in software and data calculation, such as operation result file generation software, addition routine, multiplication routine, etc. Finally, the future research directions of ternary optical computer are analyzed and prospected. Firstly, the structure of ternary optical computer is introduced, and the existing research results are summarized. Finally, the future research directions of ternary optical computer are analyzed and prospected.**

Keywords-Ternary Optical Computer; Ternary Logic; Operation-data File

I. INTRODUCTION TO TERNARY OPTICAL COMPUTER

A. Background introduction

With the development of electronic computers and the advent of the 5G network era, people cannot live without processors in their daily lives, such as general-purpose processors, digital signal processors and graphics signal processors on mobile phones; Computer systems can solve some complex engineering problems. Due to the widespread use of processors, the computing requirements are also getting higher and higher. In order to break through the limitations of too low information transmission speed and too few data bits in electronic computers, scientists in the computer field are gradually trying to develop a faster, more reliable The ternary optical computer is one of the new computers with higher, required equipment and less power consumption. The ternary optical computer has a processor number of up to one million. Part of it can serve an application program independently, the hardware computing function of each processor bit can be reconfigured at any time, and its parallel adder can be completed in 3 instruction cycles when calculating data of any number of digits, maintaining traditional programming technology and with the advantages of very little power consumption, it

DOI: 10.2478/ijanmc-2022-0036

has become the best choice for connecting electronic processors today.

The ternary optical computer uses the two mutually perpendicular polarization directions and the non-optical state of the optical state to represent information, uses the two orthogonal polarization directions of the optical state and the non-optical state, uses the liquid crystal to change the polarization direction of the light, and uses the polarizer. Check the polarization direction, use liquid crystal and polarizer to realize the transition from light state to no light state, and then realize many three-valued logical transformations. The physical characteristics of light determine the "ternary value" in the ternary optical computer; the same as the binary electronic computer, it follows the same physical principle, but the ternary optical computer has higher coding efficiency.

B. Conceptual diagram of ternary light computer

As the core device of the ternary optical computer, the ternary optical processor adopts a special construction strategy - based on the electronic computer, "optical calculation, electrical control" to construct the ternary optical computer.

The conceptual diagram of the ternary optical computer is shown in Figure 1: it consists of three main parts: the control system, the data input/output system and the optical processor. Among them, the part marked by the circle is the ternary optical processor; the thick line between the input/output array and the optical processor represents the thousand-bit data line, and the thin line between the m-channel data input server and each input storage array represents the 64-bit data Wire, The thin lines of the m-channel data output server and each output storage array represent the 64-bit result output line, The line sent out by the control system is the control line, including the reconfiguration command control line for the arithmetic unit and the control line for each electronic component.

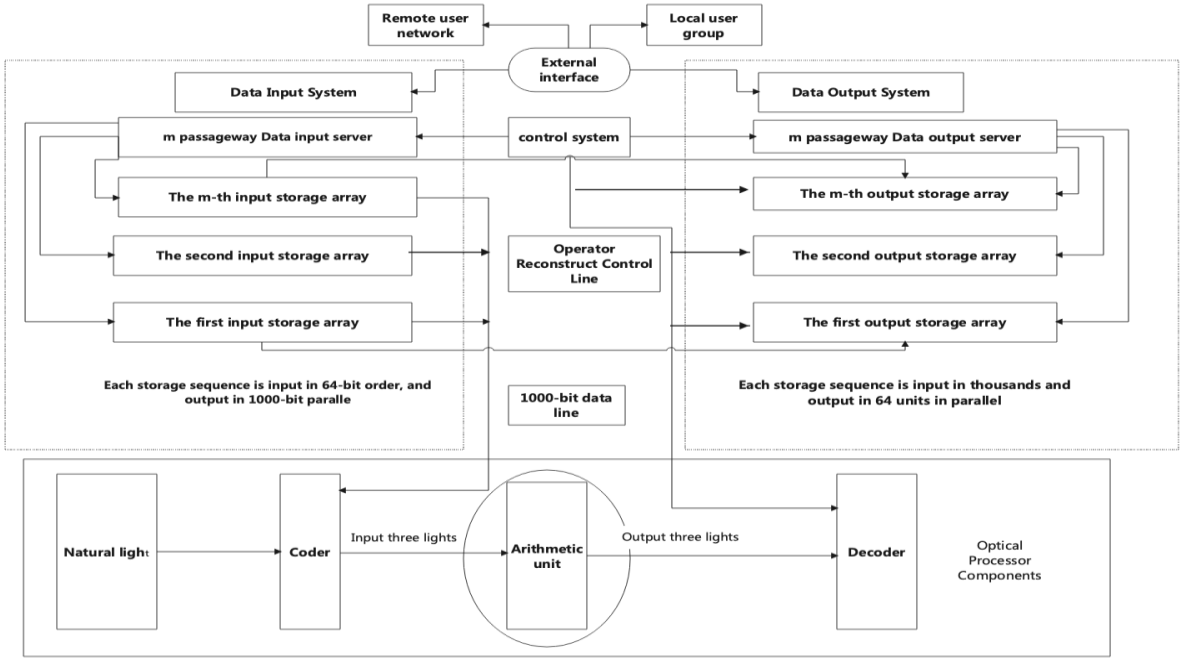

Figure 1. Conceptual diagram of ternary light computer

At present, this conceptual diagram is used as the basis for all ternary optical computers, and its working principle is as follows: the user of the ternary optical computer submits the computing task to the ternary optical computer system through the external interface, the control system receives the sent commands, and the data input The system receives the sent data, and then the control system generates control commands for each component according to the user's command: the controller applies for a data channel to the data input system for the user's input data, and the m-channel data input server allocates a certain storage array. After the array is full, The data is sent to the encoder in the optical processor unit through the kilobit data line, and then the input data storage array informs the control system; The controller sends out the operator reconstruction control command to the operator, the operator processes the data efficiently with ternary operation, and then sends the operation result to the decoder; Then output the result to an output storage array of the output system; finally, after the output storage array receives the calculation result, it sends the result to the m-channel data output server through a 64-bit result output line, and returns it to the user through the external interface.

II. ACHIEVED RESEARCH RESULTS

The ternary optical computer has been developed for more than 20 years. The development process is shown in Figure 2.

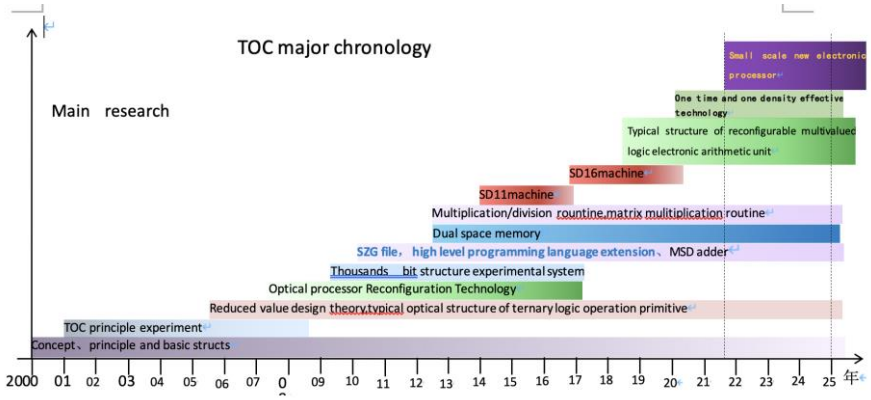

Figure 2. Development history of ternary optical computer

A. The basic principle and origin of ternary optical computer

In 1999, Professor Jin Yi discovered that two polarized states with orthogonal polarization directions can be used, the light state and the non-light state, the polarization direction of light can be changed with liquid crystal, the polarization direction can be checked with polarizer, and the light state can be changed from light state to non-light state with liquid crystal and polarizer. The transformation of the optical state, and then realize the three-valued logical transformation.

At the beginning of 2000, Professor Jin Yi carried out a series of principle experiments, which proved the feasibility of building a ternary optical computer, and also realized that the ternary optical computer would have many digits for calculation. But in this period, there is no clear method for how to convert the non-light state into the light state, I just wanted to use the interchangeability of symbols in logical operations to avoid generating an operator with a light output from two non-light inputs. Later, an

auxiliary light source was used to complete this kind of operation. In today's ternary optical processor prototype system, this auxiliary light source is implemented with a liquid crystal pixel,

In 2002, Professor Jin formally proposed the principle of ternary optical computer and the hybrid structure of optoelectronics in his doctoral dissertation, established the prototype of the theoretical system of ternary optical computer, and constructed the overall structure of ternary optical computer and the optical structure of main components, designed. The realization light path of the three-valued logic operation generated by the general logic student. At the same time, the concept of calculating the position and calculating the road was established. Based on this, the idea of the ternary optical computer distance management was established, the original characteristics of the optical computer software system were pointed out, and the ternary optical computer was extended to optical fiber communication. In the field of optical fiber communication, the idea and implementation scheme of using ternary optical signal for optical fiber communication are proposed.

B. The Proposition of Carry Direct Adder Idea

In August 2004, Jin Yi, He Huacan and others created the basic principle of the carry-to-parallel ternary optical computer adder, and created the carry-to-carry adder.

When a ternary computer builds an adder, it always identifies the addition operation as a combination of binary logic operations, and then uses a binary logic operator to build the adder. In electronic computers, in order to solve the single-line delay when carrying Carry-first strategy provides a theoretical basis for the design and implementation of a full adder in a ternary optical computer.

C. Balanced ternary numerical representation

Traditional electronic computers use "packetized parallel carry chains"; this approach increases the speed of operations by increasing the complexity of the use case, and the complexity of the computer increases with the number of bits in the computer. For an optical computer with a huge number of bits, this design will increase the structure of the optical computer adder.

In 2006, the ternary optical computer team introduced the balanced ternary numerical representation and calculation method into the ternary optical computer for the first time, which provided a theoretical basis for the study and realization of the arithmetic components of the ternary optical computer.

In 2007, Yin Xunwei, a master's student, studied the technology of "elimination of photoelectric converters" and used this technology to effectively simplify the structure of the half-adder, reduce the engineering difficulty of the half-adder, and shorten the working cycle of the half-adder.

In the ternary optical computer, the symmetric ternary {-1, 0, 1} is used to represent the data. Under the symmetric ternary representation, the positive and negative numbers have the same expression form, so the addition and subtraction operations have the same The operation process of, which also brings convenience to the fact that the subtraction operation does not need to be complemented; the negative number can be directly sent to the adder to complete the subtraction operation. Although the adder in the symmetric ternary representation still has the carry delay problem, it simplifies the subtraction operation.

D. Encoder/Decoder Experimental Research

In 2007, Yan Junyong and Sun Hao of the ternary optical computer team conducted an experimental study on the one- and nine-bit encoders and decoders of the ternary optical computer using separate optical components. This experiment proved that the ternary optical signal encoder and the feasibility of the decoder, the ternary optical computer has since entered the experimental stage,

E. Research on Data Storage of Ternary Computer

In 2007, PhD student Zuo Kaizhong discussed the problem of polarized light data storage and proposed a ternary polarization holographic digital optical storage method based on bacteriorhodopsin film. In the same year, a ternary polarization holographic digital storage method based on in dole fulgine anhydride film was proposed. This method can realize parallel addressing and read and write operations in units of pages, which is the beginning of the development of ternary optical computer optical memory.

F. Carry out research on data bit management of ternary optical computer

In 2007, aiming at the high data width (number of data bits) of the ternary optical computer, on the basis of the proposed four data bit management strategies and concepts such as bit count, count track, count bit type, count track type, etc. Professor Yi further enriched and embodied the basic strategy of high data width management, and made the initial planning for the design of the ternary optical computer operating system.

G. Propose the theory of devaluation design

In 2007, Ph.D. student Yan Junyong came up with the idea of finding the most basic unit in the structure of a ternary optical processor, and carried out the earliest research and achieved the initial results. Later, Professor Jin Yi, Yan Junyong and Zuo Kaizhong doctoral students focused on this work. After nearly a year of in-depth research, they discovered the law of depreciation design, and extracted the depreciation design theory from this law. Among them, Dr. Yan Junyong established a corresponding design specification for depreciation, and applied it to the components of the three-valued logic operator. By combining the theory of value design and multi-valued logic, he proposed a two-level design with liquid crystal and polarizer as the main components. A general implementation structure of a meta-ternary logic optical operator.

H. Carry out research on ternary optical computer application

In 2007, under the guidance of the reduced-value design theory, a ternary logic optical processor was implemented, and a ternary optical computer experimental system with the processor as the core device was completed. The three-valued logic optical processor adopts the two-dimensional plane information processing method, which has unique advantages: it has huge data bits, reconfigurable logic operation capability, and realizes three-valued operation characteristics. Therefore, it is completely possible to find suitable application points for the optical processing system, and in-depth exploration can give full play to the system.

Application research of various advantageous properties. This kind of research results will be directly transplanted to the new platform after the successful research of the thousand-bit reconfigurable ternary logic optical processor.

I. Experiment system

In 2011, Dr. Ouyang Shan designed the thousand-bit reconfigurable parallel TOC

experiment system SD11, which was the first practical TOC. Using the related technology of ternary optical computer, a prototype structure of the ternary optical computer monitoring system is established, which gives the initial idea of the ternary optical computer monitoring system.

SD11 experimental system provides the basis for future multiplication routines, monitoring systems and task management, and TOC is officially entering the experimental stage.

J. Ternary light computer monitoring system

In 2011, Dr. Wang Xianchao realized the first prototype of a ternary optical computer monitoring system with effective management of optical computer processor resources with huge data bits as the main content.

After half a year of research by Dr. Wang Xianchao, he finally determined the monitoring architecture of TOC, as shown in Figure 3. The workflow is as follows: The main function of the client is to input the truth table according to the user (about the input format of the truth table, the operand Carry out communication conversion with the truth table to generate the data represented by the internal code of communication, generate the operation request of the user, and send it to the server. On the other hand, when receiving the operation result represented by the internal code of communication, it is communicated The inverse transformation generates the operation result represented by ASCII code ; the main function of the server side is to first sort out the operation request received from the client, and insert the sorted operation request into the operation request linked list according to its priority; The operation request is scheduled according to a certain scheduling strategy, and the newly scheduled operation request is sent to the lower computer; after the scheduling is completed, the processor resources are allocated to each operation request, and the reconstruction code of the operator required for each operation is obtained at the same time, and the processing The processor allocation result and reconstruction code are sent to the lower computer; the lower computer completes the operation for the user according to the operands in the user operation request, the processor allocation result and the operator reconstruction code; finally, the operation result is sent to the client.

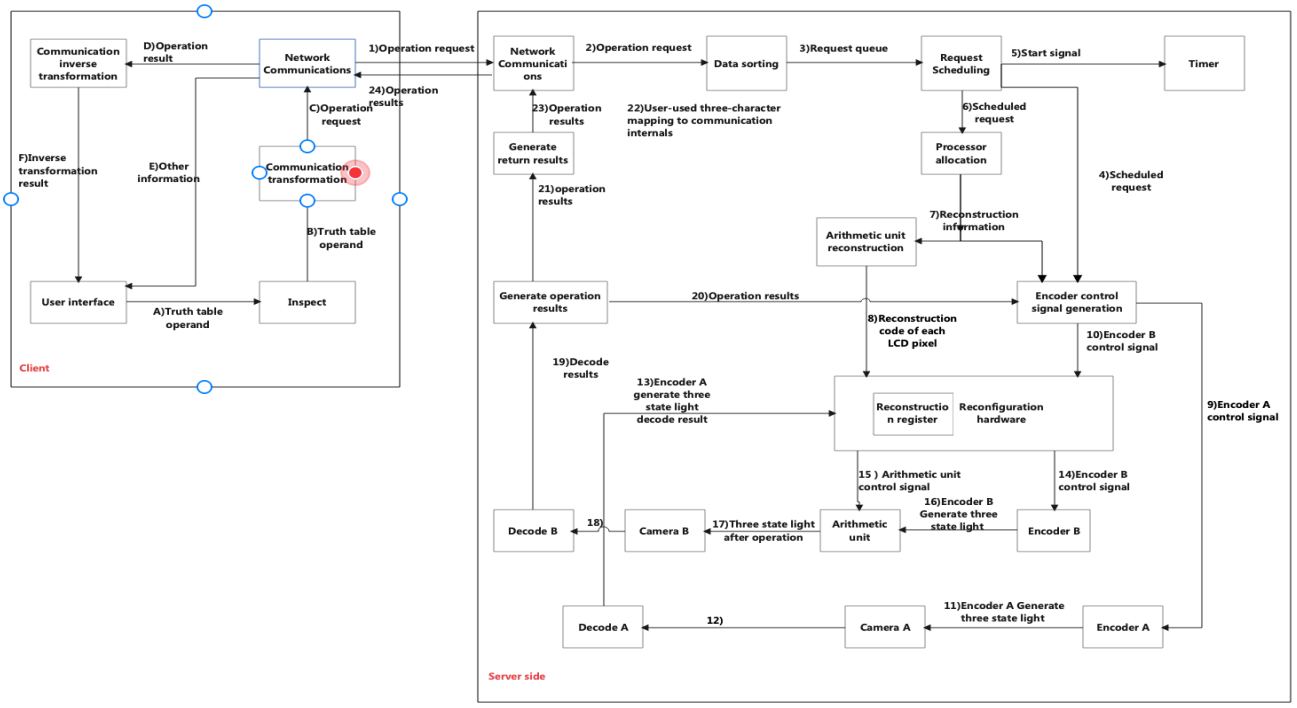

Figure 3. TOC Monitoring Architecture

Dr. Wang Xianchao conducted a series of tests on it, verified its robustness, reliability and correctness, proposed an algorithm for proportionally allocating optical processor resources of a ternary optical computer, and implemented the corresponding management program. The practical significance lies in enriching the theory and technology of data bit management in computer monitoring system. Its practical significance lies in paving the way for users to use ternary optical computer conveniently and efficiently. The use of ternary optical computers to solve challenging major problems can fully reflect the social and economic value of TOC, design and build the monitoring system software of ternary optical computers, directly use ternary optical processors for high-level programming languages , and for early Lay the foundation for the formation of a practical ternary optical computer monitoring system.

K. Operations - Data Files

In order to maintain the original programming habits and better utilize the advantages of TOC in the application, the team members use the form of operation-data files (SZG files) to include all TOC features. Therefore, the main way to use TOC is the SZG file.

In 2012, Song Kai established the first version of the SZG file, which mainly established that the SZG file was composed of two parts: the header for recording the overall information and the data area for recording the original data; the operation-data file for the ternary optical computer was established. The expression form is *SZG, and the corresponding calculation result is recorded as *_R.SZG, where the wildcard * is the full name of the original data file (including the storage path) given by the user. Based on this

version of the SZG file, the C language hungry MPI is completed. Basic expansion of the statement. From the experiment, it is clear that two kinds of computers can work together in the same application program by extending the existing programming language based on the SZG file to form the malicious application program platform of TOC.

2013, the team Jin Yi and others established the second version of the SZG file. This version of the SZG file defines the header form of the SZG file in more detail, and gives the names and functions of each item contained in the file header. and the number of bits, giving the number and location of reserved bits. This version not only makes SZG files have basic practical value, but also lays the foundation for the construction of TOC task management software, data bit allocation software, processor reconstruction software and other underlying core software.

With the development of TOC underlying software research, more detailed definitions are required for each item in the SZG file header to ensure that the TOC underlying core software can unambiguously understand the user's intention expressed in the SZG file. With the establishment of 40 -bit multiplication operation routines, division operation routines, FFT and DFT algorithm routines of TOC, SZG files are required to express more complex operation requests, and more mathematical operation routines are developed for third parties. Create conditions with common algorithm routines. With the deepening of the exploration of the potential application scenarios of TOC, it is also required that the original data or operation results can be easily extracted from the existing SZG files or their result files to generate new SZG files - forming a SZG file chain. Therefore, the third version of the SZG file format was established in 2015, which is also the finalized version, as shown in Figure 4.

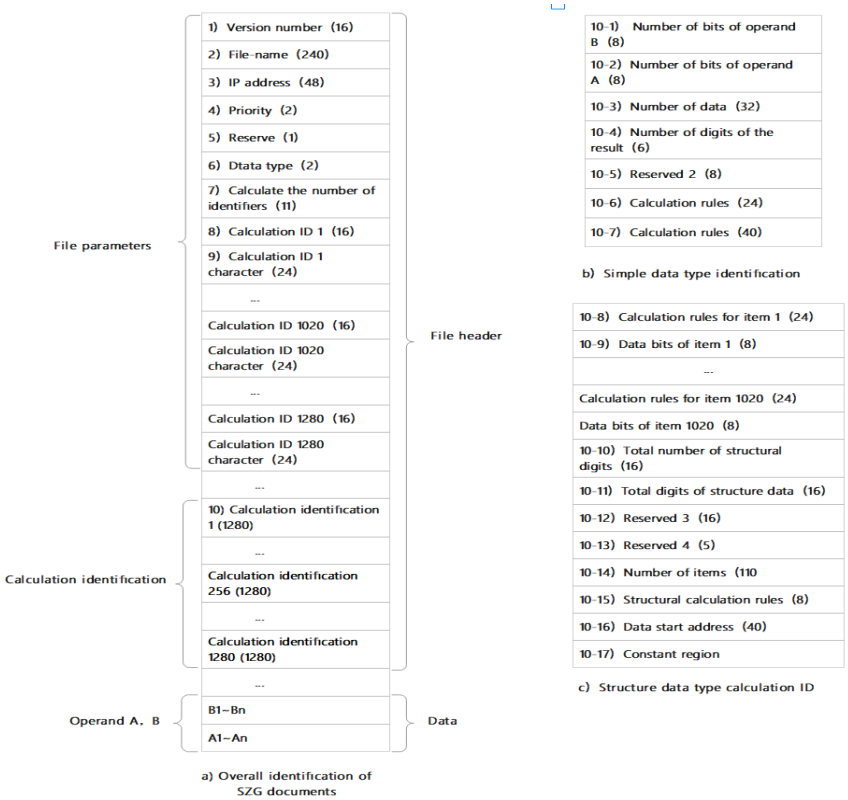

Figure 4. Operations - Data File Format

SZG file is the only way for TOC to obtain user operation data. SZG file consists of two parts: file header and operation data (file body). The file header records the structural parameters of each operator required by the user and the overall parameters of the operation data. The information in the file header mainly provides parameters for reconstructing the optical processor. The data area is the operand input by the user, including operand b and operation Number a. In order to ensure an accurate understanding of the user's operation data, the form of the SZG file constructed by the user must be consistent with the form of the SZG file read by the TOC. Therefore, the SZG file format definition is the core of this technology.

L. 40 - bit multiply routines

Multiplication is one of the important functions required in TOC's march towards the field of numerical computing. In 2013 , a postgraduate student Hu Xiaojun designed and implemented a 40- bit multiplication routine for ternary optical computer by taking advantage of the features of TOC, which is reconfigurable, with a large number of data bits and no carry delay. , through the M transformation in the three-valued logic to generate the partial product of the intermediate process of multiplication, and then use the iterative calculation method of adding two pairs to sum the values to obtain the final product. Hu Xiaojun established a specific operation routine by adopting the single M operator scheme and the "sum number" addition iteration scheme of the pipeline calculation combined with the design and planning of the TOC monitoring system, and gave the specific method for the upper-level users to use this routine; the first implementation of TOC The multiplication function is a key arithmetic operation function of TOC, and it also provides research ideas and method comparisons for the future development of other functions of TOC (such as matrix multiplication).

M. Ternary light computer physical machine

In August 2016, when optimizing the structure of the ternary optical processor and reconstructing the system, team member Dr. Li Shuang proposed the structure of the ternary optical computer - SD16 structure, and built SD16 - No.0 machine in November 2016 (Figure 5).

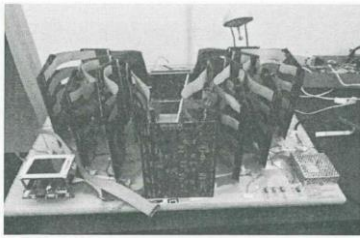

Figure 5. SD 16 - No. 0 machine

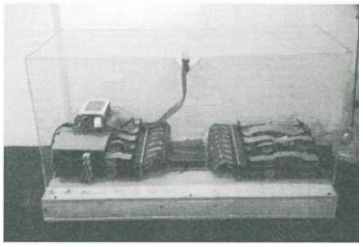

Figure 6. SD 16 - No. 1 machine

September 2017, in order to reproduce the structure of SD 16 and at the same time optimize the assembly method of each component, the team built SD16 - No. 1 machine (Figure 6).

SD 16 physical machine structure is a leap in the development of TOC, which proves the authenticity of TOC, and also means that all theories are based on realization, providing an experimental environment for all subsequent researches.

N. Computational data file generation software

Objectively speaking, after defining the final version of the SZG file format, when the user is familiar with the defined format, any editing software can be used to generate the SZG file from the original protective gear, but this method increases the calculation time, so in 2018, Dr. Li Shuang designed the SZG file generation software. This software takes up a small amount of system resources, does not increase the burden on the client system, avoids data loss, stores the user's data in non-volatile memory, and ensures that the existing SZG files are retrogradely tracked and modified at any time, which is convenient for users to update themselves.

The function of the software is to generate the initial SZG file through the user 's input of original data and calculation rules. Considering the friendliness of the user's input interface, the correctness, completeness and simplicity of the user's input information determine the final determination of this document as shown in Figure 7. As shown in the user input interface of the SZG generation software, the user only needs to input data through the prompt, and then the software will generate the file operation, which greatly improves the computing efficiency.

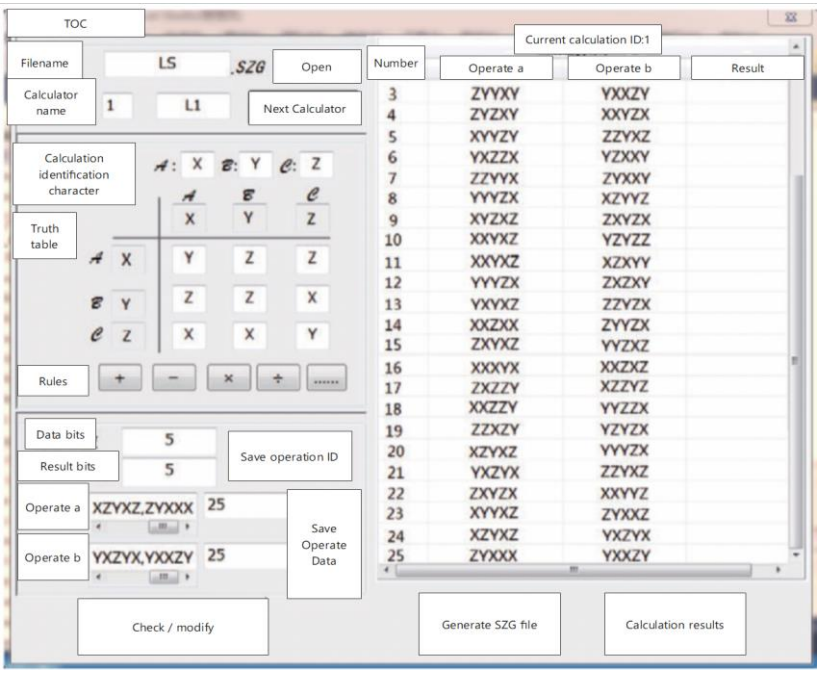

Figure 7. User Input Interface

The SZG file software generation software provides a corresponding programming platform for TOC, gives the basic theory and core technology of building a new computer programming environment, improves the existing theoretical foundation of TOC, and prepares for TOC to enter the application stage.

O. Big task management software

In2018, Dr. Zhang Sulan studied the following contents based on the characteristics of the ternary optical processor with a large number of processor bits, which can be grouped and allocated bit by bit:1) Before the ternary optical processor starts to calculate the specific data, it needs to be Reconstruct various calculators

required by the user; 2) The original data is output to the reconstructed calculators in a simple and fast way. To this end, the research team proposed a calculation-data programming model, and then structured the ternary optical computer software system, classified the calculation tasks proposed by users, and determined the control objects of the large task management software.

After nearly 5 years of hard work, the large task management software developed has the following functions: correctly accept the user's computing request; generate corresponding tasks according to the calculation strategy, efficiently manage and schedule these tasks; reasonably allocate the received large tasks Ternary optical processor bit resources; and generate reconstructed instruction frames and operand encoding frames that meet the requirements of the ternary optical processor format; finally, the operation results of the decoder should be obtained and correctly returned to the corresponding users.

The design and implementation of the large task management software provides ideas and experimental basis for the detailed classification of the subsequent TOC tasks. In fact, the implementation of the large task management software only completes a small part of the TOC task classification, and the remaining classification needs to continue. Research,

III. FUTURE RESEARCH DIRECTIONS

In 2007, under the guidance of the reduced value design theory, the ternary logic optical processor was realized, and the ternary optical computer experimental system with the processor as the core device was completed. At that time, the experimental system could not solve the practical scientific application problems. Until the advent of the first thousand-digit SD 11 experimental system in 2011, it paved the way for subsequent TOC time studies. Subsequently, the birth of the TOC prototype SD 16 in 2016 also verified the theory of the three-week optical computer again, and also carried out related research: the realization of cellular automata computing mode and the realization of optical vector-matrix multiplication.

In recent years, small-scale new electronic processors and reconfigurable multi-valued logic electronic operators are also being studied.

IV. CONCLUDING REMARKS

TOC has been developed for more than 20 years. From the creation of theory and its improvement to the stage of practice, members of the TOC team have been committed to various researches on TOC, and have achieved some of the above-mentioned considerable results. Therefore, TOC has gradually become popular among people. In the field of vision, we firmly believe that the future of ternary optical computer is bright, but at the same time, we are also soberly aware that the course of its research and development will be arduous and tortuous. We hope that more people who are interested in ternary optical computer research will join our team and work together for the future of ternary optical computer.

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