Image Recognition Method by Optical Quasi-Quantum Computing

Tetsuo Hattori*, Osamu Matoba**, Bahram Javidi***

*Faculty of Engineering, Kagawa University, Takamatsu 761-0396, Japan
E-mail: hattori@eng.kagawa-u.ac.jp
**Institute of Industrial Science, University of Tokyo, Tokyo, 153-8505, Japan
E-mail:matoba@iis.u-tokyo.ac.jp
*** Electrical & Computer Engineering Dept., University of Connecticut, Storrs, CT 06268, USA
E-mail: Bahram@engr.uconn.edu

1. Introduction

A real quantum computer seems to have considerably high potential for solving problems that the current computer cannot solve in practical time [1]-[4]. The potential ability mainly comes from the fact that the quantum computer can perform a large number of parallel processing at the same time, using quantum mechanical superposition states and unitary transformations operation on the states in a Hilbert space. And theoretically, the high dimensional Hilbert space can be effectively generated by entanglement effect in quantum physics.

However, it still seems very difficult to implement the practical quantum computer by the present technology. In this situation, we consider that, a realization of quasi-quantum computer that can do what the quantum logic does, will be very useful, because the quasi-quantum computer shows a new computing paradigm and it can show the ability of real quantum computer. We also consider that optical implementation is one of the possible ways to realize the quasi-quantum computer.

In this paper, first, we show that arbitrary unitary transformation is possible in an optical system. Second, we show that an optical quasi-quantum computing system for image recognition can be implemented. We describe the image recognition algorithm based on the quantum computing logic, i.e. concrete unitary transformations for quantum state image representation and matching (or similarity computation) between input image and reference images [5], [6].

Although our system currently does not utilize entanglement physics like a real quantum computer using electronic spin system, we can construct a high dimensional Hilbert space (e.g. one thousand and twenty four dimensions) using one axis in an optical system. The 1024-dimensional Hilbert Space is equivalent to a ten-qubit quantum computing system. So, if we use two axes in that optical system, we can obtain a higher dimensional Hilbert space. The measurement of result from the unitary transformation in the Hilbert space using optics will be given as the intensity of the each wavelength (or frequency) light, which corresponds to the squared amplitude of each basic quantum state. So we consider that our system using optics may become another approach (or methodology) to realize quantum computing paradigm.

2. Optical Quasi-Quantum Computing

The illustration of a part of the proposed image recognition system based on an optical quasi-quantum computing system is shown in Fig.1. An ultrashort pulse like femtosecond pulses, which consists of a lot of spectra, is used as a light source. In the proposed quasi-quantum computing system, each spectrum corresponds to one basic quantum state.

Suppose that we have n quantum bits, which creates 2^n states. We consider that a superposition state can be described as

$$|a\rangle = \sum_{m=0}^{2^n-1} f_m |m\rangle \tag{1}$$

$$\text{where} \sum_{m}^{2^n-1} |f_m|^2 = 1 \tag{2}$$

In Eq. (1), f_m can be expressed as $|f_m|e^{i\phi_m}$, where $|f_m|$ and ϕ_m are amplitude and phase of f_m, respectively. For the implementation of arbitrary unitary transform, it is necessary to arbitrarily control both amplitude and phase of f_m in Eq. (1) under the condition of Eq. (2).

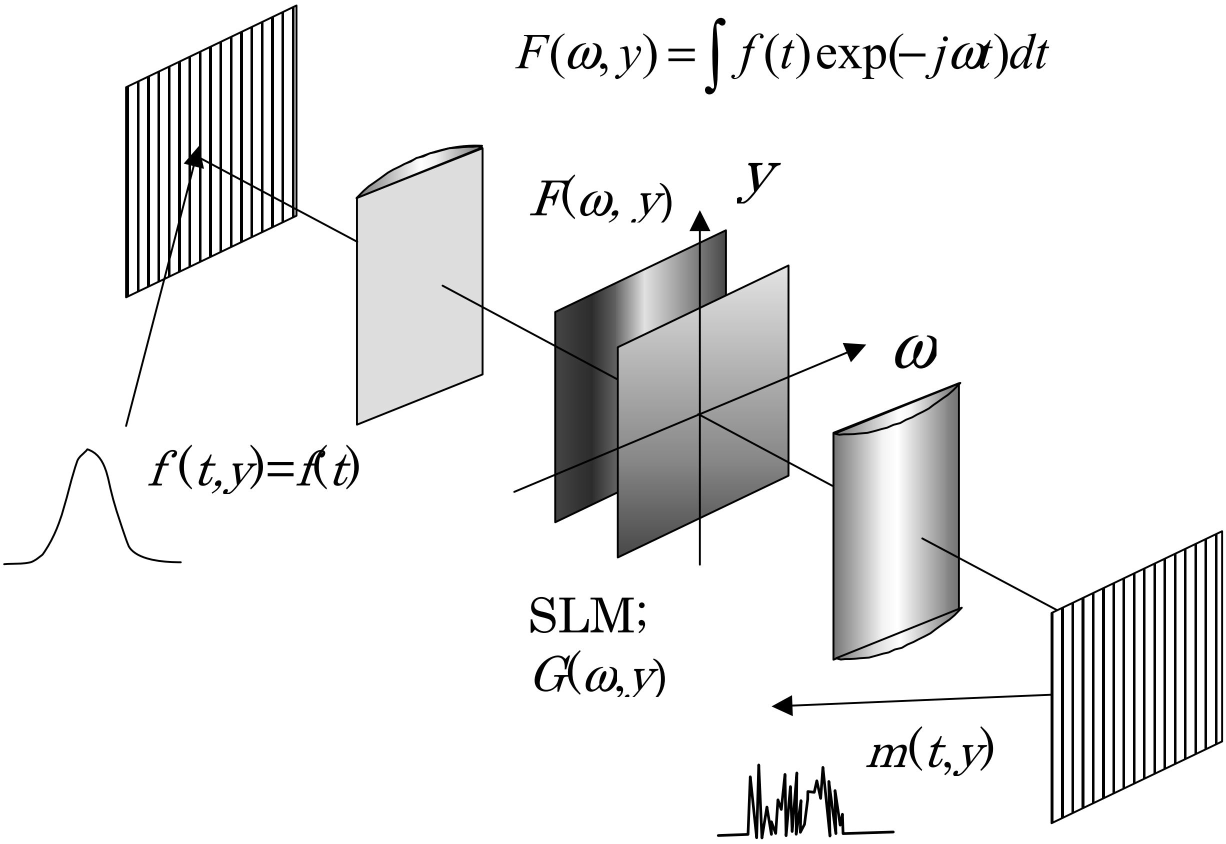

Fig.1. Schema of a part of proposed optical quasi-quantum computing system.

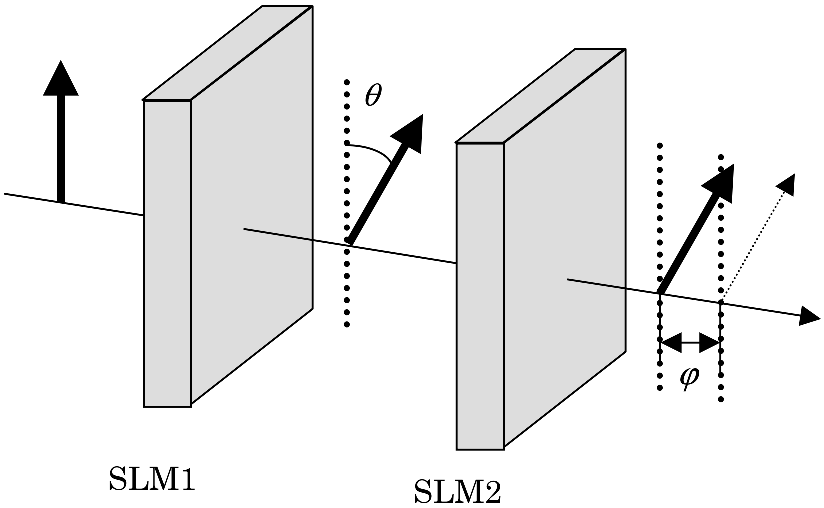

Fig.2. Control of the amplitude and the phase controlled by two SLMs. SLM1 and SLM2 operate amplitude and phase modulation, respectively.

In the following, we describe how to realize the arbitrary superposition state shown in Eq. (1) by using the proposed system in Fig. 1. An ultrashort optical pulse, such as several hundreds femtosecond pulse, consists of light waves that have wavelength width of several nanometers. Such a limited optical pulse, which is spatially collimated and temporally transformed, is incident on a grating and then diffracted. The diffracted light, whose each spectrum travels different direction, is spatially Fourier-transformed by a cylindrical lens. In the Fourier domain, the spectral content of the pulse is distributed as a function of the spectrum. It is written by

$$F(\omega, y) = \int f(t)\exp(-j\omega t)dt \quad (3)$$

where $f(t)$ is a temporal signal of the input pulse and t is the time.

The cylindrical lens creates uniform spectral distribution along the y-axis at the Fourier plane. The spectral distribution of the input pulse can be modulated in both amplitude and phase using two spatial light modulators (SLMs) such as liquid crystal SLMs as shown in Fig. 2.

One of the SLM is used for the modulation of the amplitude and the other is for the modulation of the phase. To control the amplitude of each spectrum, we use the rotation of the polarization. The amplitude of the rotated polarization projected into the y-axis is changed by the rotational angle. Each rotated light wave with a monochromatic spectrum is then phase-modulated by another SLM. The signal at each spectrum is modulated by

$$\cos\theta\, e^{i\varphi} \quad (4)$$

Thus we can implement the arbitrary unitary transform described in Eq. (1). There are commercially available one-dimensional SLMs that can control both amplitude and phase of 256 pixels at present technology. It is possible to control 4096 pixels in amplitude or phase. For two-dimensional SLMs, 1024 x 768 pixel SLM can be available, but is operated only in phase or amplitude. Let the modulated function of the SLM be $G(\omega, y)$ that includes both amplitude and phase modulation. And let the modulated spectral distribution be $M(\omega, y)$. It is written by

$$M(\omega,y) = F(\omega,y)G(\omega,y) \quad (5)$$

By using another set of a lens and a grating, we obtain the temporally modulated pulse, $m(t,y)$, as follows.

$$\begin{aligned} m(t,y) &= \int M(\omega,y)\exp(j\omega t)d\omega \\ &= f(t,y)\otimes g(t,y) \end{aligned} \quad (6)$$

where $g(t,y) = \int G(\omega,y)\exp(j\omega t)d\omega$ and $\otimes$ denotes convolution.

This modulated pulse is used as a new input pulse for next unitary transform.

3. Image Recognition

In this section, we present again an image recognition procedure in quantum computing described in the literature [6]. This procedure can also be simulated by the aforementioned optical quasi-quantum computing system.

First, in order to represent to represent a quantum state of normalized input image, we need a unitary transformation that will generate an arbitrary superposition state $|f\rangle$ from a basic state. Such a transformation can be synthesized as described in [6]. Suppose that the initial state to be transformed is $|0\rangle$ =(1,0, ⋯, 0) $^{T.}$ The goal is to obtain the vector $(a_1, a_2, \cdots, a_N)^T$, starting the state $|0\rangle$, where $N = L^2$ and L means the size of image,.

3.1. Analysis Processing

Step 1: Choose a suitable orthonormal system, and correspond the orthonormal base to each registered image.

Step 2: Obtain a unitary transformation ***U*match** that makes correspondence between the set of above orthonormal bases to the set of quantum basic states in a given physical system of detector unit.

The unitary transformation ***U*match** in Step 2 will work for image matching and similarity computation between input image and the registered reference images, at the following recognition stage.

3.2. Recognition Processing

Step 3: Make a unitary transformation ***U*input** for the representation of input image $f(x,y)$.

Step 4: Operate the ***U*input** to the initial state $|0\rangle$, and generate a superposition state as input state $|input\rangle$.

$$\left|input\right\rangle = \frac{1}{\sqrt{\sum_{x=0}^{L-1}\sum_{y=0}^{L-1}\left(f(x,y)\right)^2}} \sum_{x=0}^{L-1}\sum_{y=0}^{L-1} f(x,y)\left|x\right\rangle\left|y\right\rangle \tag{7}$$

Step 5: Operate the unitary transformation ***U*match** to the input state vector, and construct a state vector $\left|matched\right\rangle$.

Step 6: Measure the state vector $\left|matched\right\rangle$.

3.3. Measurement

If the detector unit is a quantum register, we only have to read the qubits (integer number shown by the observed bit pattern on the register). In this way, with high probability, we can observe the number (basic state of quantum register) corresponding to the registered reference image pattern that has high similarity with the input image pattern. Computational cost for matching in the recognition stage does not depend on the number of registered reference images, M.

In a classical system, the computational cost for image (or pattern) matching proportionally depends on the multiplication of the number of reference images and the number of the pixels, i.e. ML^2.

In the aforementioned optical quasi-quantum computing system, the measurement probability (corresponding to similarity) after the above procedure will be observed as the light intensity of each spectrum. So, we can know at the same time as to which basic quantum state (corresponding to a spectrum in our optical system) will give maximum similarity for input pattern.

4. Conclusion

We have proposed an image recognition system based on an optical quasi-quantum computing system. This system uses a pulse shaper with an ultra short optical pulse such as several hundreds femtosecond pulse consisting of light waves with several nanometers wavelength. The spectral distribution of the input pulse is modulated in both amplitude and phase of optical electric field by a spatial light modulator (SLM). And the modulation can be used to do the implementations for arbitrary unitary transformations.

We have also shown a image recognition schema by some unitary transformations: a unitary transformation for quantum state representation of input gray level image and a unitary transformation for pattern matching between input image pattern and registered image patterns [6].

In our optical quasi-quantum system, it can perform the same logic as what the real quantum computing logic does. Theoretically, in both real quantum computing system and the quasi-quantum optical one, the recognition time is indifferent to the number of registered images.

The similarity between the input image and the orthonormal system (that means a set of "standard" image patterns in a sense) is given as a distribution of the light intensity in the optical system. And the highest similarity can be easily observed by the light intensity. So, if we have another mechanics that can detect the number of the registered images whose correspondent image gives the highest similarity for the input image, then we are supposed to obtain a very powerful function for pattern recognition system by quantum computing.

References

[1] D.Deutsch: "Quantum Theory, the Church-Turing Principle and the Universal Quantum Computer", Proc. R.Soc.Lond., Vol.A 400, pp.97-117, 1985.

[2] P.Shor: "Algorithm for Quantum Computation: Discrete Logarithms and Factoring," Proc.of the 35th Annual IEEE Symposium on Foundations of Computer Science, pp.124-134, 1994.

[3] L.K.Grover:"A fast Quantum mechanical algorithms for Database Search," Proc. 28th Annual IEEE Symposium on Theory of Computer. Science, pp.212-219, 1996.

[4] L.K.Grover: "Quantum Mechanics helps in Searching for a needle in a haystack," Phys. Rev. Letters, Vol. 78(2), pp.325-328, 1997.

[5] A.Yu.Vlasov: "Quantum Computations and Images Recognition," quant-ph/9703010, March 1997.

[6] T.Hattori, K.Takeda, T. Yamasaki: "Recognition of image data in quantum computer, in Quantum Computing," Eric Donkor and Andrew R. Pirich, Editors, Proceedings of SPIE vol. 4047(2000), pp.27-34, April 2000.