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OPTICAL FEATURE RECOGNITION

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OPTICAL FEATURE RECOGNITION

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Song Fei Jun[1]

Compared with digital image recognition technology, optical feature recognition has faster speed and larger capacity for information processing, therefore it lies at the cutting edge of real time recognition technology trends. Here I will summarize the development of optical feature recognition and discuss physical models on Vander Lugt pairwise wave filter and joint interchangeable correlation recognition method, and introduce an optical-electrical real time correlation recognition system which utilizes spatial light modulator.

I. MANUAL RECOGNITION, COMPUTERIZED AND OPTICAL RECOGNITION

Feature recognition is to detect the presence and position of certain information or to identify if two images are the same, it is also called figure recognition. For example, spotting certain type of missiles and tanks and indicating their coordinates from aerial pictures taken by satellites or the other flying objects; Prompt recognition of airplane models from the viewing field of a telescope; Spotting certain symbols (i.e. upper case letter "A") and indicating their position on a page of a journal. Feature recognition also applies to visual recognition of robots, and recognition of parts used in an assembly line.

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* Numbers in margins indicate foreign pagination. Commas in numbers indicate decimals.

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Therefore, it is a topic that will have a significant impact in the military and economics.

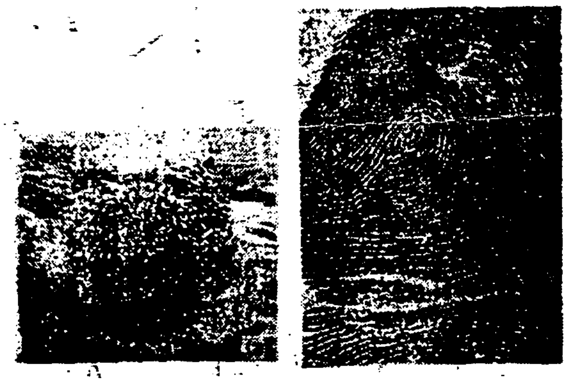

Fig. 1. Case fingerprint (a) and file fingerprint (b)

In recent years, public security bureaus and judiciary organizations expressed great interests in using this technology in fingerprint identification. During the investigation of a criminal case, a fingerprint that is left by the criminal can often be found, which is called case fingerprint. By comparing the case fingerprint with suspects' fingerprints, criminals can be tracked down. To this day, data accumulated has yet indicated that no two different people will have a complete match in their fingerprints. Therefore, fingerprints can be regarded as something unique for each individual. For years, fingerprint comparison had to be done manually under a microscope, i.e. compare the direction and shape of the case fingerprint a with the one in file, b, and judge if a=b or a=\b. Fig. 1 is a pair of case and file fingerprint. Apparently, the accuracy of this method, to a larger extent, depends on a worker's "decoding" proficiency and his experience, therefore it could be very subjective. In the case where case fingerprints are fragmented or look murky, identification can be extremely difficult. If clues on criminals are inadequate, larger numbers of suspects' file fingerprints have to be checked. This will pose a huge volume of work, and tend to delay the case's resolution.

Therefore, a faster and a more accurate and objective recognition method is needed by security bureau and judiciary organization.

Digital image processing is a familiar recognition technology. It takes photos of two prospective figures a and b, and samples certain information and converts them to digital images vial A/D transformation. A computer extracts certain features from these images and compares them with various evaluation standards. This technology has already found practical uses and been used routinely.

However, the amount of information contained by 2-D image is tremendous. For example, if we use 512x512 point square to sample a black and white image, each point will take 8 bit, a whole image takes 2 Mb. A simultaneous comparison of these two images requires additional 2 Mb. If we take into account system monitor, recognition software, the memory of the computer has to be at least 5 Mb, which exceeds the capacity of an ordinary PC. Furthermore, a PC uses parallel processing, which means processing a gigantic amount of information for image recognition which takes a great deal of time. Therefore, digital image processing requires faster speed and bigger memory PC or super minicomputer.

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The size of the recognizer needs to be kept at a minimum in some cases (i.e. on board an airplane). The amount of time that takes to finish the recognition also needs to be reduced to minimum. For example, prompt response to an attacking air object demands quick and precise recognition. Faster identification of criminal's fingerprints is also needed to solve a case.

More and more scientists and engineers are getting interested in this new cutting edge of science-optical information processing. As we know, lenses can carry out Fourier transformation on 2-D images. A slightly complex optical information processing system can do correlation recognition on input test image and reference image. In theory, the process of recognition can be completed within moments of shining by coherent light (laser). Nowhere can digital image recognition be compared with such a speed. In addition, optical processing system has lower cost, smaller size and more compact structure. It can also work stably. All of these features compensate for the inadequacy of digital image processing system, and draw attention of many experts in the field of feature recognition.

II. USE OF OBJECT LIGHT TO RECONSTRUCT REFERENCE LIGHT IN HOLOGRAPHIC RECONSTRUCTION AND VANDER LUGT'S PAIRWISE WAVE FILTER

Holographic reconstruction is a familiar technology. It consists of two steps depicted in fig.2. The first step is holographic recording, during which the complex object light and one beam of simple reference light (usually it is plane wave or spherical wave) meet at a holographic film and form complex interference fringes, which is then recorded by the film. The second step is reconstruction. Usually the reference light alone is used to shine at the holographic image. As a result of holographic diffraction, object light is reconstructed and enables us to see the fake object behind the hologram, which is a vivid 3-D image of the original object. This is so called holographic reconstruction.

Rarely would anybody think of using object light to reconstruct reference light. In theory, object light and reference light have identical phases, since it is possible to use reference light to reconstruct object light. By the same token, the reverse process would hold true for object light. However, object light is complex. Only when the reconstructed object light is in complete match with the one in recording, should it be possible to reconstruct the original reference light, as it is shown in fig. 2(b). Hence, the appearance of the reconstructed reference light can be used as an indication if the reconstructed object is identical to the original one. Moreover, if we place a lens in the back of the reference light, reference light plane will condense into the focal point and form a bright spot, a so called "self correlating" spot. It is a clear indication of homogeneousness or similarity of the reconstructed object and the recording one. This is one of the methods used in feature recognition.

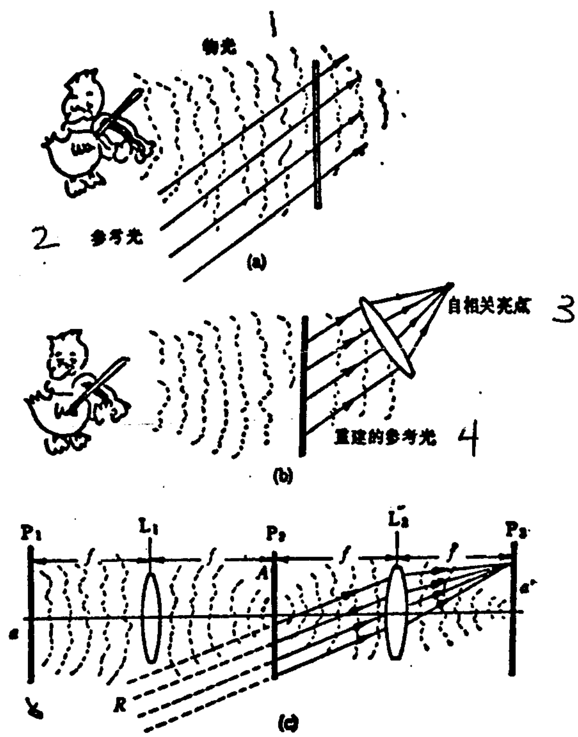

Fig. 2. Use of object light to reconstruct reference light in holographic reconstruction and Vander Lugt's pairwise wave filter.

Key: 1. object light; 2. reference light; 3. self-correlation point; 4. reconstructed reference light.

In 1964, Vander Lugt used the above method and succeeded in building a so called pairwise wave filter apparatus. He used it in feature recognition and this becomes an important milestone in the history of optical feature recognition.

Vander Lugt's experiment is depicted in fig.2(c). This is a typical optical information processing system. P1 is input plane, P_2 is wave filter plane, P_3 is output plane; L_1, L_2 are Fourier transformation lenses, P_1 is shined by a parallel laser beam. If an input image a is put on P_1, a spatial spectrum A of a will appear on P_2 due to Fourier transformation by L_1. This A is transformed back to a' image by L_2. An inclined reference light wave R plane is introduced on plane P_2 by Vander Lugt. It interferes with A, the Fourier spectrum of a, and forms complicated interference fringes. If a light sensitive film is placed on /723
P_2, the profile of the interference figure intensity can be recorded. Since we are recording the interference image of the reference light R and A, we named it Fourier transformation hologram.

If we assume the angle between the plane reference light R and the light axis is θ, R can be expressed as

$$R = R_0 \exp\left[j2\pi\left(\frac{\sin\theta}{\lambda}\right)y \right] \tag{1}$$

The profile of light intensity of the interference image after it merges with A

$$\begin{aligned} |R+A|^2 = {} & |R|^2 + |A|^2 \\ & + R_0 A^* \exp\left[j2\pi\left(\frac{\sin\theta}{\lambda}\right)y \right] \\ & + R_0 A^* \exp\left[-j2\pi\left(\frac{\sin\theta}{\lambda}\right)y \right], \end{aligned} \tag{2}$$

Similarly, if a reference image b is placed on plane P_1, a spatial spectrum of b, B, will appear on P_2. If b=a, then B=A. If we use it shine the Fourier transformation hologram on the film, the inclined plane reference light R will be reconstructed (see fig.2 (c). When it is subsequently condensed by L_2, a bright spot (self correlating spot) will be formed on the output plane P_3. This is why b=a.

Holographic wave reconstruction is a very strict process. If b≠a, then B≠A. Neither a reconstruction of reference light R is possible, nor will a correlating spot appear on the output plane.

From the point of view of optical information processing, when b=a, the spectrum resulting from the Fourier transformation by L_1 must be A. After A is processed by pairwise filter A* (multiplication), $A \cdot A^* = |A|^2$. After $|A|^2$ is processed by a reverse Fourier transformation by L_2, a correlation output is obtained. The correlation peak will fall on the focal point of the reference light R. The pairwise filter A* is generally complicated. The merit of Vander Lugt lies in his recording of this complicated function onto an intensified recording media. As we discussed above, the key of his method is the introduction of an inclined reference light plane.

Although, Vander Lugt opened a new era in the optical feature recognition, two serious drawbacks of his pairwise filter method impede the application of this technology.

Firstly, the excessive strictness on coordinates and ratio among images during the recognition process. In another word, the second input image must have the same coordinates and ratio as the first one during the reconstruction of the reference light.

For example, if the first input is an English letter"F", and the second input is an upside down"F", no correlating peak will be available. Even if the second input is still "F" but has a smaller size, there will be no output of correlation. The reason is quite simple: the optical system used for figure recognition obeys very strict recording and reconstructing principles, it does not have such an advanced recognition capability as self-learning, self-adjusting that are associated with human beings. In an optical system, even two almost identical figures only slightly differing in their coordinates and ratio, will be treated as two unrelated input signals. The system is incapable of automatically restoring the original status if the two figures are rotated or changed proportionally. As it was shown in our experiment, when the relative coordinate difference of two figures is 3.5^0, or their size differs 2%, the correlating output will decrease from 30 dB to 3 dB.

The second drawback is the requirement of restoring the pairwise filter into its original position after the process. The early wave filter was made from holographic plate. After it records the first input image spectrum and the interference image of reference light, it needs developing and fixing. The processed plate must be restored to its original phase, otherwise no correlating peaks will be seen, even if the same object is used as a second input.

Since the birth of pairwise wave filters, ceaseless attempts have been made to overcome these drawbacks [2-5].

III. YOUNG'S INTERFERENCE FRINGES ON IDENTICAL IMAGES AND JOINT TRANSFORMATION CORRELATOR

Holographic reconstruction is a marvelous method in figure recognition, but it is not the only method available. Other optical physics effects can be used in feature recognition. One of the most important one is Young's experiment. As it was shown in fig.3(a), when a pair of parallel slits S_1 and S_2 are shined by the same light source or by parallel beams, a group of parallel Young's fringes will show up on screen H which lies a large distance from the back of these slits. If S_1 and S_2 are replaced by a pair /724 of identical figures and subsequently shined by parallel lights, there will be many corresponding "S_1" and "S_2" in the image. All of these slits will produce overlapping Young's fringes. Usually a lens L is used to collect the light from this pair of figure, Young's fringes will be seen on screen H in the back of L (fig.39b).

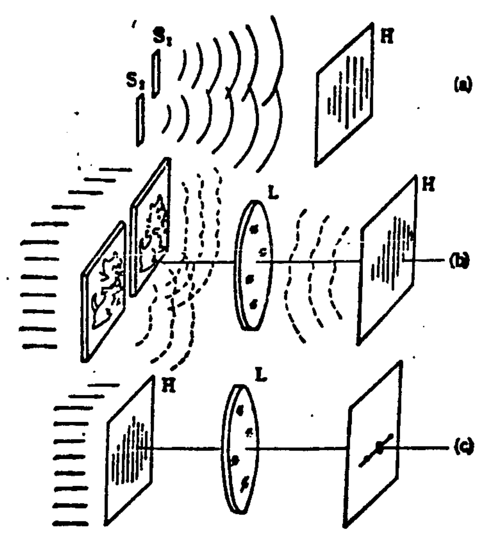

Fig. 3. Young's interference experiment and Joint transformation correlator.

It goes without saying that only two identical figures with the same coordinates should produce overlapping Young's slits. If the two figures were different, no Young's fringes will be seen on H. Therefore, presence of Young's fringes can be a measure if the two figures are identical.

Soon after the invention of Vander Lugt's pairwise wave filter, Weaver and Goodman proposed a so called Joint transformation correlation recognition scheme [6] which takes advantage of the principle in Young's experiment. This is a two step recognition process. In the first step, a coherent light is used to shine a pair of figures a and b, a recording plate on the focal point in the back of lens L is used to record the interference image of a and b. In the second step, the recording plate on the previous input plane is used to replace a and b and shined with coherent light. If a=b, then the interference image will be Young's fringe. A shining spot ("0" grade spectrum) will appear in the center of H which is on the focal point behind lens L. On the both sides of it, shining spots (+1 grade spectrum) will appear symmetrically, this is called "correlation peaks" of a and b (fig. 3(c)). Obviously, only when a=b will the correlation peaks appear. Reversely, this can be used as an indication as a=b. Since it contains all the information on Young's fringes, therefore it is even more striking and clearer. Usually, the appearance of this pair of correlation peaks can be a basis for judging if a=b. When a≠b, the interference fringes will not be the same as Young's, consequently no correlation peaks will be obtained.

As we discussed above, the image behind lens is the Fourier transformation of input figures. Since a and b are input at the same time, Young's fringes are the Fourier spectrum formed jointedly by a and b, therefore it is called joint spectrum. Such a kind of correlation recognition is called joint correlation recognition.

During the joint correlation recognition, the amplitude profile of the interference image of a and b is converted to an intensity profile in the recording plate. The recording plate has no strict phase restoring requirements according to the correlation output principle. As long as Young's fringes are recorded on the plate, a correlation peak should appear after shining with coherent light. This is more convenient than the pairwise wave filter. Although the joint correla-tion is still sensitive to the coordinates and ratios of images, almost all of the latest optical feature recognition schemes in recent years adopted this technology.

IV. APPLICATION OF THE SPATIAL OPTICAL MODULATOR IN REAL TIME OPTICAL-ELECTRICAL MIXTURE CORRELATION RECOGNITION

Traditional optical feature recognition systems use He-Ne laser as light source which is bulky and not quite efficient. Observation of correlation peaks has to be carried out manually. Both input figures and wave filter apparatus rely on holographic plate as information carrier, the plate has often to be developed and fixed, and real time processing can not be materialized. Therefore, the traditional optical feature recognition has to be done in a lab.

However, the recent technological breakthroughs have reshaped the correlation recognition. With the arrival of mini but powerful semiconductor laser generator, various spatial optical modulator and CCD, the traditional "pure optical physics" recognition technology has been transformed into a new generation of optical-electrical mixture real time recognition system.

Magnetic optical spatial light modulators (MOSLM) have become a familiar electron seeking modulator [7]. It is based on magnetic optical effect which enables the images stored in computers to be displayed on the modulator.

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Liquid Crystal Light Valve (LCLV) is a typical light seeking spatial bright modulator [8] (fig.4). It takes advantage of "mixed field effect" which results from addition of electrical field to a liquid crystal, this leads to a change in dual refractive nature of the output terminal. The output light is transmitted to the output terminal of LCLV via polarizing prism BS. It becomes polarized light and is vertical to the paper. When no light is hitting the input terminal of LCLV, or the light signal has not reached threshold, the output terminal of LCLV becomes equivalent to an ordinary reflector, there will be no change in the polarizing state of the output light, and it will not be able to pass through BS. When the input light exceeds the threshold, the reflected output light becomes horizontally and elliptically polarized light, and is approximate to the linear polarizing light in the horizontal direction. As a result, most of them pass through BS. The light intensity profile on the output terminal of LCLV corresponds to the amplitude profile of the input terminal. In another word, the amplitude spectrum of input light terminal has been converted to an intensity spectrum or power spectrum of the output light. It becomes equivalent to the light sensitive film, in which case the developing and fixing procedure has been omitted.

The other function of LCLV is the transformation of the coherent state. As we know, it is easier to work with coherent light in Fourier transformation, correlation, integration. But in reality, most of objects have to be lightened by incoherent light. This brings a need to convert incoherent light to coherent. Even if the input and output light of LCLV is totally irrelevant in wavelength and coherent state, LCTV could still finish the conversion.

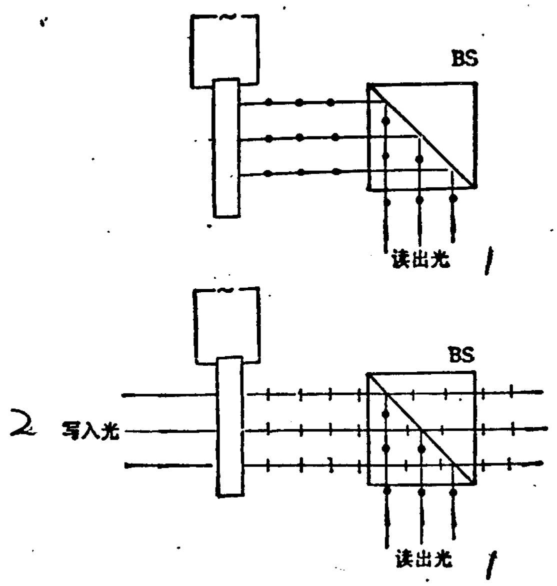

Fig. 4. The working principle of LCLV.
• represents the polarized light that is perpendicular to the surface of the paper

| represents the polarized light that is parallel to the surface of the paper

Key: 1. polarized light; 2. surface of paper;
3. BS is a prism

With the birth of commercial light modulators, optical-electrical mixture real time correlator is being built soon afterwards. Fig.5 is an example.

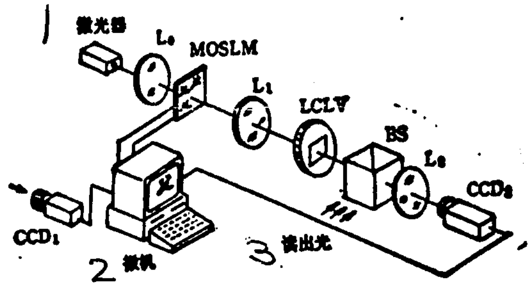

Fig. 5. Optical-electrical mixture real time correlation recognition system (BS is a prism)

Key: 1. Laser generator; 2. computer; 3. display light

Reference figures with different ratio and coordinates are photocopied by CCD and stored in minicomputers. Target figures are processed in the same fashion and displayed on MOSLM. After the first Fourier transformation by L_1, joint amplitude spectra are formed on LCTV. They are subsequently converted to joint interchangeable power spectra.

The joint interchangeable power spectra form correlation output after the second Fourier transformation by L_2. They are detected by the second CCD and sent to the central minicomputer for processing. If the test images match specific coordinates, ratio of the reference images, correlation peaks will appear at corresponding positions.

The application of MOSLM, LCLV and CCD apparatus made the correlation recognition system very attractive.

Traditional optical processing system is connected to digital image processing system via MOSLM and CCD, and forms optical-electrical mixture recognition system. In this system, optical image processing and computer image processing have different functions. The optical image processing handles 2-D Fourier transformation and correlation operation, while the computer image processing deals with image storage and input, correlation peak detection. This certainly takes full advantage of the high capacity of the optical system and flexibility of the minicomputer.

The replacement of holographic plate with LCLV made it possible to convert joint amplitude spectrum to a power one and made the real time correlation a reality.

At the time we worked on optical-electrical mixture recognition, we attempted to improve the efficiency of correlation recognition. We made different kinds of wave filters [10,11,12,13] which greatly improved the recognition system.

Great strides have been made in the optical-electrical real time correlation recognition technology in recent years. A fluctuating magnetic optical correlator based on MOSLM has been successfully tested in simulated target recognition systems. Till this day, this has not been found to be of practical use in commercial and military. But a compact, fast speed and low cost real time correlator with both of the advantages of optical processing and digital image processing is still the target of scientist and engineers.

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