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An Optical Implementation of Adaptive Resonance Utilizing Phase Conjugation

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Abstract

A novel adaptive resonance (ART) device has been conceived that is fully optical in the input-output processing path. This device is based on holographic information processing in a phase-conjugating crystal. This sets up an associative pattern retrieval in a resonating loop utilizing angle-multiplexed reference beams for pattern classification. A reset mechanism is used to reject any given beam, allowing an ART search strategy. The design is similar to an existing non-learning optical associative memory, but does allow learning and makes use of information the other device discards. This new device is expected to offer higher information storage density than alternative ART implementations.

The Optical Implementation

The design of the optical ART unit is shown in Figure 1. It is an modification of

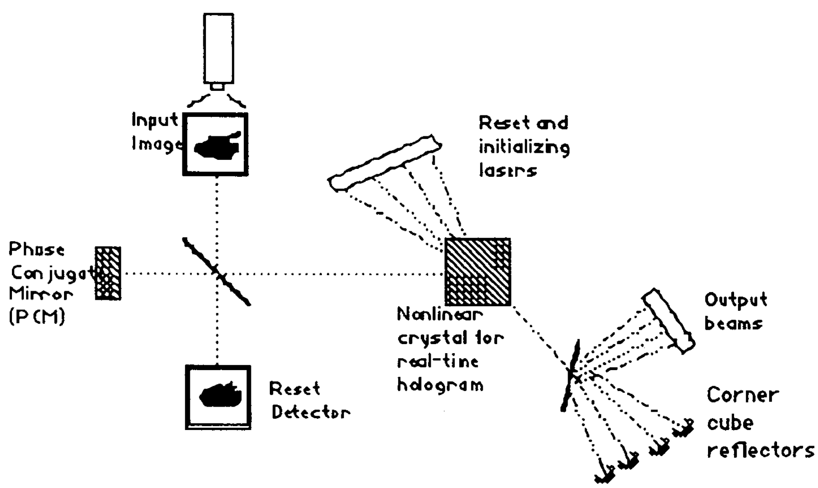

Figure 1. A phase-conjugating ART unit.

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the resonating loop reported by Soffer et. al.[1] in 1987, and shown in Figure 2. The key element to notice in Figure 1 is the nonlinear crystal (such as barium titanate) in the center. This is a phase-conjugating device capable of recording a hologram in real-time.[2] It acts as part of a resonant cavity designed to converge on the correct images to make it behave as an ART unit. Contrast this with Figure 2, where a fixed hologram is used. The Soffer et. al. device in Figure 2 is capable of associative pattern retrieval, but is not capable of learning. Another difference to notice between Figures 1 and 2 is the replacement of PCM1 in Figure 2 by corner cube reflectors in Figure 1.

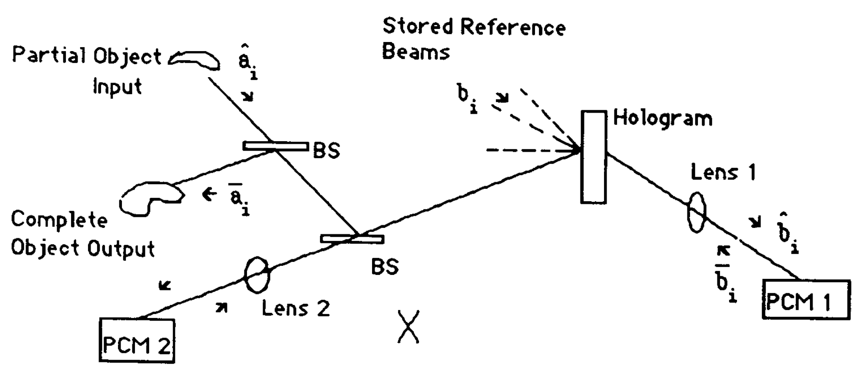

Figure 2. The holographic optical resonator

A brief review of the operation of the holographic resonator in Figure 2 will help to explain the optical ART unit in Figure 1. The holographic resonator is primed with a partial input pattern, $\hat{a}_i$, in the upper left of Figure 2. This is reflected off the second beamsplitter toward the fixed, previously recorded hologram, exciting several reference beams $\hat{b}_i$. These are retro-reflected by PCM1 back toward the hologram, setting up a resonant loop between PCM1 and PCM2. The loop is biased by the presence of the hologram and by the injected signal $\hat{a}_i$ and will suppress all stored patterns (and their reference beams) except for the one most closely matching $\hat{a}_i$. This will cause a readout of the stored image $\bar{a}_i$ closest to the input $\hat{a}_i$. Note also that the device can be considered as a pattern classifier by considering the output reference beam b_i to be an angularly multiplexed classification code. Finally, note that light containing information from both $\hat{a}_i$ and $\bar{a}_i$ will be present at the point marked X in Figure 2, but that this information is not used in any way.

The optical ART unit of Figure 1 was inspired by the Soffer et. al. device, but uses a barium titanate crystal instead of the hologram to allow learning. This simple change is the key to making the device behave as an ART unit, but two problems arise: 1. It is difficult to control the resonant behavior of three phase-conjugating crystals, and 2. It is necessary to provide a reset mechanism to correctly implement ART. These problems are both solved by replacing PCM1 of Figure 2 with the corner cube reflectors of Figure 1. This clearly solves problem 1, since there are now only two crystals. The solution of problem 2 hinges on placing a detector in a position to record the overlap of the input pattern and the recorded template. This is precisely the information that is discarded in location X of Figure 2. The reset detector of Figure 1 is an integrating photodetector, and the path lengths and pump beam angles are adjusted so as to cause constructive interference between the input pattern $\hat{a}_i$ and the stored template $\bar{a}_i$. If this detector's measurement is too small, reset is indicated, and the corner cube reflector corresponding to the most active reference beam angle is deflected. This gives the other memories of the system a competitive advantage for the duration of the search cycle. If reset is not triggered, the system will be allowed to resonate in its preferred mode, causing learning of the new pattern. In any event, the output of the device is the classification provided by the reference beam angle, which can be read off by use of a beamsplitter as shown in Figure 1. It is also possible to read out the stored template information in a similar manner to the "Complete Object Output" shown in Figure 2. In other words, the device can be used as either a heteroassociative or autoassociative ART-based memory.

The optical layout schematic of the device is shown in Figure 3. For experimental verification of the design, human observation of the reset signal and deflection of the corner cube reflectors is acceptable. This role could ultimately be played by piezoelectric motors or optoelectronically. The beamsplitters that allow the reference beams should be of increasing reflectivities, i.e. 33% and 50% for this configuration.

The fully optical ART unit is capable of processing large patterns and has a large template capacity. The device's capacity should ultimately approach the capacity of holographic storage systems, which have the potential to greatly exceed electronic capabilities.[3,4] Furthermore, the device is all-optical in the information processing path--the reset detector's electronics are never used when an input pattern has already been learned or matches an existing template sufficiently. ART has been shown to be useful with extremely large input fields, such as may be expected in high-resolution images.[5] The high storage density of this device should make it outperform alternative ART implementations[6-10] that do not offer the same potential to deal with the large number of pixels in a high-resolution image. (Those implementations are more likely to be used with applications in which speed is more important than the capability to handle large numbers of pixels.)

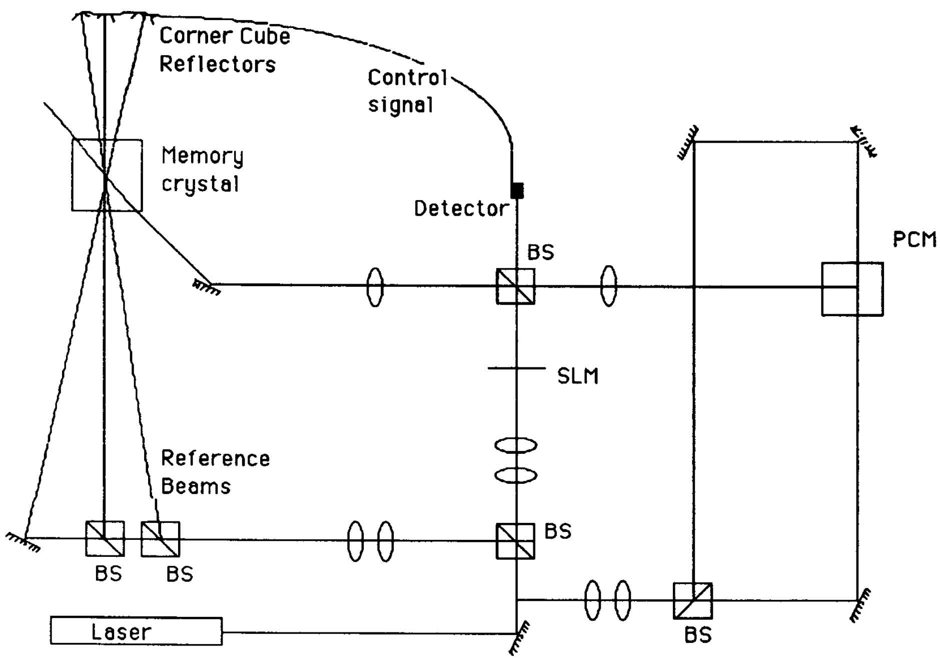

Figure 3. Optical layout of the optical ART unit.

Conclusion

A novel adaptive resonance device based on a phase-conjugate resonator has been proposed. It offers a fully optical information processing path and the information storage capacity of holographic media. As such, it is an attractive alternative to other ART implementations for applications requiring large input fields.

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