Automated Target Recognition and Tracking Using an Optical Pattern Recognition Neural Network

Tien-Hsin Chao

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
Phone (818) 354-8614   Fax (818) 393-4820

Optical Automatic Target Recognition and Tracking System

The on-going development of an automatic target recognition and tracking system at the Jet Propulsion Laboratory is presented. This system is an optical pattern recognition neural network (OPRNN) that is an integration of an innovative optical parallel processor and a feature extraction based neural net training algorithm. The parallel optical processor provides high speed and vast parallelism as well as full shift invariance. The neural network algorithm enables simultaneous discrimination of multiple noisy targets in spite of their scales, rotations, perspectives and various deformations. This fully developed OPRNN system can be effectively utilized for the automated spacecraft recognition and tracking that will lead to success in the Automated Rendezvous and Capture (AR&C) of the unmanned Cargo Transfer Vehicle (CTV).

One of the most powerful optical parallel processors for automatic target recognition is the multichannel correlator. With the inherent advantages of parallel processing capability and shift invariance, multiple objects can be simultaneously recognized and tracked using this multichannel correlator. This target tracking capability can be greatly enhanced by utilizing an powerful feature extraction based neural network training algorithm such as the neocognitron. The OPRNN, currently under investigation at JPL, is constructed with an optical multichannel correlator where holographic filters have been prepared using the neocognitron training algorithm. The computation speed of the neocognitron-type OPRNN is up to 10^{14} analog connections/sec that enabling the OPRNN to outperform its state-of-the-art electronics counterpart by at least two orders of magnitude.

Origin and Evolution of the OPRNN System Capability

The Optical Processing Group of the Microelectronic Device Laboratory (MDL) at JPL started its development of a multichannel optical correlator a few years ago with the support of NASA RTOP funding. A 9 channel optical correlator was built and tested successfully for the simultaneous tracking of multiple objects. This multiple correlator was designed for potential NASA applications including orbiter and lander navigation and guidance of future planetary exploration missions as well as spacecraft rendezvous and docking.

Recently, the Strategic Defense Initiative Organization/Innovative Science and Technology Office (SDIO/IST) sponsored a program, through an agreement with NASA, to develop an OPRNN for the discrimination and tracking of SDI laser radar targets. Due to the complex nature of this problem, a neocognitron-type OPRNN was proposed for this application. The neocognitron uses a feature-extraction approach to discrimination. The evidence extracted by individual image features is fused in stages and, at each stage, allowance is given to scale and aspect angle variations. As a result, the neocognitron-type OPRNN is able to robustly recognize input images over a large range of scales and aspects.

We have devised an innovative system architecture that is able to implement the neocognitron-type OPRNN with shift invariance. A multichannel optical correlator is used as the basic building block of the OPRNN since shift invariance is an inherent advantage of the optical correlator.

In order to provide large system capacity and high speed thresholding detection for the neocognitron-type OPRNN, a binary optic grating and a thresholding detector array has been developed at the MDL. The binary optic grating is fabricated with an e-beam ligthography system that is able to replicate an input image into a 9 x 9 uniform array such that 81 features of an input image can be processed simultaneously. With further development of this binary optics technology, up to 400 multichannel processing capability can be achieved. A 32 x 32 thresholding photodetector array chip has been designed, fabricated and tested. This photodetector array consists of 32 x 32 array cells each containing a photo-transistor for photon detection, comparator circuitry for thresholding control and digital circuitry for address reporting. This detector is able to process all the incoming signals in parallel by detecting and reporting, within two miliseconds. Further research is underway to design up to 128 x 128 photodetector array with submillisecond response time.

Level of Maturity

A prototype breadboard of a neocognitron-type OPRNN has been integrated at JPL. This system consists of a liquid crystal television spatial light modulator (LCTVSLM), a 9 x 9 binary optic grating, a thermoplastic holographic camera, and a 32 x 32 thresholding detector array. Simultaneous development of the binary optic grating and photodetector array is being continued to further enhance the system capability. Additional funding will be needed for conducting system packaging work to develop a full-functional compact system that is suitable for airborne and spaceborne operation.

Experimental Results

We have performed experimental investigations using a multilayer neocognitron-type OPRNN for discrimination of laser radar images of SDI objects such as re-entry vehicles and decoys. Experimental results demonstrate that, with the appropriate selection of the training features and our innovative multilayer processing scheme, successful recognition and tracking of multiple SDI objects with intra-class deformation tolerance and inter-class discrimination capability are achievable.

This experimental demonstration shows that the shift invariant OPRNN can be easily extended to applications useful to NASA missions involving spacecraft rendezvous and docking.

Source/sponsorship and Current Funding Estimates

The current level of support for the OPRNN system components development and breadboard demonstration is about $300k/year funded by SDIO/IST and DARPA. Additional funding will be necessary to accelerate the technology development as well as the compact system integration such that it will be suitable for operation in a spaceborne environment.