Partial differential equation based preprocessing and immune response inspired algorithms implemented on CNN universal machine

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This dissertation (i) describes parallel histogram modification techniques with embedded morphological preprocessing methods within the CNN-UM framework, describes and illustrates how the implementation of the algorithm results in an adaptive multi-thresholding scheme when histogram modification is combined with embedded morphological processing at a finite small number of gray-scale levels; (ii) presents an immune response inspired algorithmic framework for spatial-temporal target detection applications using CNN technology. The given algorithms can be implemented effectively only by using a computer upon which thousands of elementary, fully parallel spatial-temporal actions can be implemented in real time. Experiments demonstrate that the developed system can detect unknown patterns and dynamical changes in image sequences.

The two fields / opened problem are the following:

- the implementation of a real-time filter algorithm in the diagnostics of noisy ultrasound images
- the detection of real-time, multi target, spatial-temporal novelty detection in image flows

In the course of my research I was searching for a method which, besides simultaneous contrast enhancement, noise filtering and shape enhancement, could be implemented on the input image with real-time processing. I showed that nonlinear partial differential equation (PDE) described, morphological and wave operation-based parallel histogram modification can be realized with spatial approximation by operating on finite number of level-sets. I showed that the chosen level-set based algorithm can be implemented on an analog CNN-UM chip (Acex) and I proved experimentally that it satisfies the theoretical expectation qualitatively and quantitatively to a good approximation. For 128x128 image resolution, a speed of 200 frame/s could be achieved. My running time measurements prove that the histogram modification algorithm can be applied efficiently in real-time image preprocessing methods. Its application in medical imaging can give solutions (i) for real-time ultrasound image processing of echocardiographic diagnostics and (ii) fMRI image evaluation.

I intended to design topographical algorithms and their experimental realization where huge number of target objects are monitored in real time to detect previously unknown events. So my goal was spatial-temporal novelty detection. I showed that the functional model of the immune response can be described in a cellular neural network (CNN) algorithmic framework and can be applied as an efficient image processing method. I worked out a real-time algorithm and its CNN-UM chip (Acex) implementation based on my model, which is able to detect novelty events in image flows reliably, running 10000 templates/s with video-frame (25 frame/s) speed and on image size of 128x128. In this thesis the presented model and its algorithms were designed to be able to be used in complex surveillance systems, to learn fast, to be adaptive to dynamic environments and to send alarm messages based on different rules, if necessary. This system can be well-applied in any situation, where human presence is beyond its ability or the supervision can not be real-time, but immediate decision based on visual input is required.