Applied High-Speed Analogic Algorithms for Multitarget Tracking and Offline Handwriting Segmentation

Theses of the Ph.D. dissertation

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"We are at the very beginning of time for the human race. It is not unreasonable that we grapple with problems. But there are tens of thousands of years in the future. Our responsibility is to do what we can, learn what we can, improve the solutions, and pass them on."

Richard Feynman

Introduction, Objectives

During the last ten years more and more scientists in the research community have started to use Cellular Neural Networks (CNN) and especially CNN Universal Machines (CNN-UM) to solve diverse problems and to test the applicability of the paradigm in varied problem domains. The formal model has become ever more precise and rich (Cellular Wave Computer) while the physical implementations are becoming more advanced (optical, emulated digital, FPGA-based etc.), and the „Bi-i" computer which combines a classic digital processor and sensor with a CNN-UM was also introduced. VLSI silicon-based implementations of the CNN-UM paradigm have advanced as well, from the initial 20x22 resolution through 128x128 to the soon to be available 176x144, with some implementations capable of executing multilayer CNNs as well.

It was clear to me at the start of my research, that the discipline and the available tools have reached a maturity level where new problems may be tackled that before were thought to be impossible, or impractical to attempt. In my dissertation, I will present algorithms from two such areas: the simultaneous tracking of several rapidly moving targets and the preprocessing tasks of offline handwriting recognition systems. The algorithms presented in both areas are analogic algorithms, i.e. they utilize both parallel analog and logic operations.

In multitarget tracking the task is to track many rapidly moving objects in a plane, so that the system is able to determine the kinematic properties of the individual targets (position, speed and acceleration) while robustly handling errors from occlusions and illumination changes that may occur. This task seems fairly easy to a human being, but previous algorithms where only able to show modest results. During the development of my algorithm, I relied heavily on our group's accumulated knowledge gained from research into modeling the mammalian retina. In the retina, the input image is filtered and transformed in different ways and these image streams are then processed in parallel, with only a very sparse and compactly coded representation sent toward the higher areas of the brain involved in vision. I use this principle in the algorithm described in the Chapter 2. of the dissertation to ensure that the measurements from a given input image are the best possible, increasing the accuracy of the whole tracking system. The application of the same principle also made it possible for the system to adapt to changes in the environment as while is running ensuring robust tracking.

Methods of Investigation

During my research, I relied on the tools of many disciplines. In the design of the tracking

algorithms I applied algorithms used in radar tracking and the results of studies that describe their accuracy and efficiency. I analyzed the efficiency of algorithms with methods from algorithm theory to be able to compare the proposed algorithms with those previously published in the literature. For the CNN-UM algorithms, I utilized the template classes and the accrued experience with them previously published in the literature. It was an important consideration to choose templates that could be executed reliably on the CNN-UM chips available in our laboratory ensuring the immediate practical use of the algorithms. In image processing algorithms, I relied on the results of binary mathematical morphology and their CNN-UM implementations.

In general, an important aspect of my algorithms is that for maximum speed and efficiency, they utilize CNN and classical digital solutions executed on their respective platforms. I tested the algorithm on PCs with Intel x86 architecture processors using the Matlab software suite augmented with the MatCNN simulator and executed them on the ACE-BOX and Bi-i systems. Both systems contain mixed-mode (analog-digital) CNN-UM chips; the former contains the Ace4k with 64x64 resolution, the latter the Ace16k with 128x128. I also actively participated in the design and development of the development environments of these systems.

New Scientific Results

1. Thesis: Adaptive, multitarget tracking algorithm and system

An important subtask in video flow processing is the tracking of targets moving at arbitrary speeds with high precision and reliability. The challenges in these applications are the filtering of the objects, the modeling of their motion, and – especially – the tuning of the algorithm parameters during execution because of change environmental conditions. I created an algorithm to solve these problems, which utilizes CNN-UM processors to filter efficiently out the objects in the images and allows the easy adjustment of its parameters in order to generate consistent output. I combined this algorithm with one of the best so-called data association algorithms described in the literature and created a complete system that is able to track multiple objects in real-time. Publications: [1],[11],[12],[16]

1.1 I developed an algorithm, which is able to efficiently track multiple objects in a video flow and extract and classify their kinematic properties

The algorithm – relying on ideas from the mammalian retina – extracts the important image features relevant to the task in several parallel channels, and combines them

through a special method developed by me. The results are then further filtered, and using optimal data association methods the kinematic properties extracted, once the objects have been located on the filtered image. The method also enables the user to filter the tracked objects based on morphologic or kinematic properties.

1.2 I demonstrated that using the above algorithm, object saliency is better on the filtered image in an average sense than on the individual channels.

I combine the output of the individual filter channels using a custom method (which can be tuned thru several parameters). I showed that the data association algorithms provide better results in an average sense (when no *a priori* assumptions can be used) if executed on the combined filtered image than if run on the individual channels.

1.3 **I demonstrated that by feeding back the results of the tracking to the multichannel front-end, the accuracy of the tracking could be enhanced.**

I used statistical and qualitative analysis on the tracking results to compute measures to judge the accuracy of the tracking. I developed an algorithm to adjust the parameters of the multichannel front-end based on these measures to increase the tracking accuracy.

2. Analogic segmentation algorithms for offline handwriting recognition

Segmentation problems are among the most difficult in offline handwriting recognition: segmenting pages, lines and words before the commencement of the actual recognition. The more accurate the segmentation, the easier and more accurate the recognition will be. I developed analogic algorithms that are able to efficiently locate and segment an image of a handwritten page into lines, the lines into words and the words into letters. The algorithms exploit the wave computing capabilities of the CNN-UM architecture. Publications: [3], [15]

2.1 I developed methods to segment handwritten images into lines, and lines into words.

I created an efficient algorithm to segment handwritten pages into lines, even if the lines are somewhat skewed or non-straight. I also showed a method to reliably segment lines into words for further processing.

2.2 I created a new algorithm to segment handwritten words into letters and showed a new wave computing-based solution to find pairs of points in parallel, which are closer to each other than a given distance.

I developed a word segmentation algorithm, which does not rely on semantic information, thus it can be used for unfamiliar languages and texts. I utilized a wave computing based method to detect points, which are within a given distance from each other. An important advantage of this algorithm compared to conventional methods is that the execution time is independent of the number of points and their location.

Application Areas of the Results

All of the algorithms described in the dissertation present solutions to real-world problems. I showed that execution speed and accuracy of the multitarget tracking algorithm (1st thesis) enables its use in control applications. To demonstrate this, with the help of my colleagues, I built a laser targeting-tracking system, which is able to track and target with a laser multiple objects moving at high speed in real time.

The multitarget tracking algorithm is also used in a software system whose task is the surveillance and monitoring of indoor and outdoor industrial areas. There is great demand today for complex surveillance systems, which take over the boring and error-prone tasks from human personnel, but are able to trigger alarms, when needed. The use of the algorithm in this setting has many advantages:

- It enables the triggering of alarms based on complex motion patterns (motion trajectory, direction and speed, the number of moving objects, etc.)
- Kinematic properties may be used during object identification and classification, which – in many cases – simplifies the task.
- The object tracking system supplies object location and speed prediction information, which may be used to optimize processing at the later stages of the surveillance algorithm

I also designed the algorithms for the preprocessing tasks of offline handwriting recognition (2nd thesis) with ease of use in mind. This means, that each of the templates is executable on one of the commercially available VLSI CNN-UM chips, and the (possibly) low resolution of the processors is not a barrier to application (128x128 in the case of Ace16k). I collaborated closely with my colleagues who are working on the recognition of handwritten characters and words so that it would be possible to interface the systems easily.

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Finally, I am sorry if I inadvertently omitted somebody. It was not intentional.

List of Publications

The Author's Journal Papers

2005

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