20 μsec focal plane image processing

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ABSTRACT: *Ultra high frame rate image processing was achieved by applying CNN-UM chips as focal plane array processors. By applying parallel optical input, and reading out binary decision from the chip only the computational overhead is negligible. This makes possible even 50,000 fps image capturing and complex processing. Experiments were done and are described in the paper.*

1. Introduction

The research of the Cellular Neural Networks [1] started in the late 80s in the University of California at Berkeley. Five years later the CNN Universal Machine (CNN-UM) concept was published [2] by professors Tamás Roska and Leon O. Chua. The first fully operational CNN Universal Machine chip with optical input [3] was designed in 1995 in Professor Angel Rogríguez-Vázquez's laboratory in Seville, Spain. Parallel with the early CNN-UM chip designs, we started to develop the CNN Chip Prototyping System (CCPS) [4], which is a complex hardware software test-bed for functionally and algorithmically evaluating the analogic chips.

Since that a number of CNN-UM chips were integrated in the CCPS system [5,6,3,7,8,9,10] and many interesting measurement results and applications were tested on the analogic hardware. Among the applications, one can find texture segmentation [11], halftoning [12], implementation of mathematical morphology [13], etc. By using the CCPS, important accuracy measurements [3] and chip based robust template designs [12,14] were also accomplished. In this paper another type of CNN-UM application is introduced, namely the ultra-high frame-rate image processing.

Ultra-high frame-rate (above 10.000 fps) image processing is an unsolved problem in the digital domain. Affordable priced and sized digital system cannot handle this problem since two reasons. On one hand, it has not enough computational power, on the other hand I/O bottleneck arises when the image is transferred from the sensor to the processor. A recent digital breakthrough in this field [15] could avoid the second problem by integrating the image sensor and the processor array on the same silicon surface. Though the computational overhead was negligible, the digital chip could not exceed 1000 fps even with simple computational tasks. The fabricated digital chip could process 16x16 black-and-white images.

The current CNN technology can reach 50 times larger frame-rate than the above mentioned champion digital system. If the CNN-UM chip is used as a focal-plane array, the zero computational load requirements are satisfied automatically. The chip acquires images parallel through the optical input and the images are transferred to the processor elements also in parallel. In 20μsec approximately 5 template operations and 10 local logic operations can be completed, which makes possible even a complex morphological decision or a surface texture analysis.

In this paper, the experimental setup is described first. Then measurement results are introduced. It is followed by the analysis of the possible industrial applications. Finally, we conclude our results.

2. The experimental setup

The experimental setup is shown in Figure 1. We made the experiments with the cP400 CNN-UM chip [3] which has 20x22 analog processors with a binary sensors in each. This means, that the chip can capture and process 20x22 sized black-and-white images. The CNN-UM chip is driven by the CCPS system. The CNN platform, which carries the chip is mounted on the back panel of the camera. From the camera, only the optics was used, no shutter was required. The threshold of the incoming image could be set with a potentiometer. A rotating disk was fabricated with adjustable rotating speed. The maximal rotation speed was 3000 r/s, which means roughly 10m/s linear perimeter speed. In this experimental setup we used constant illumination rather than a stroboscope. On the rotating disk we posted different images, which were projected to the chip through the lens system of the camera.

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The CCPS system is a general framework for testing and evaluating different CNN-UM chips. Hence it was not designed to reach the top speed of the chips. However, by using the system we can estimate the reachable maximal speed on an optimal hardware. Due to this, in our experiments we were able to reach 10,000 fps, and we estimate the highest achievable speed around 50,000fps, depending on the complexity of the recognition algorithm.

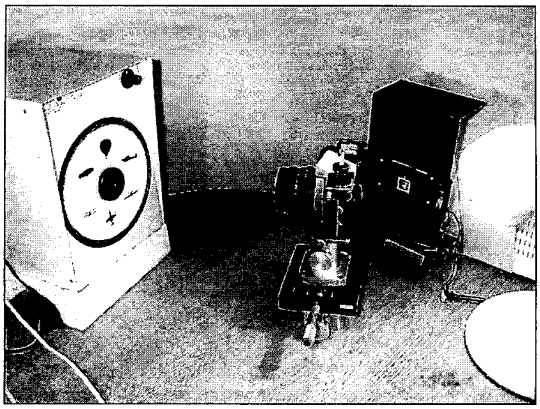

Figure 1. *The experimental setup. For visualization purposes we opened the back panel of the camera.*

3. Measurement results

The computational framework of the 20×22 CNN-UM chip allows the user to design and run complex algorithms for classification tasks based on the shape, size and orientation of objects. Here we demonstrate that this chip is able to classify six different flying objects (hot-air balloons, airplanes) based on their silhouettes' low resolution projections on the chip's optical sensors. The objects were printed on a paper ring as shown in Figure 1 and 2. The paper is placed on the controllable speed rotating disk, and the CNN-UM chip captures 20×22 images at a fixed position. As it is demonstrated in Figure 2, the captured image does not contain the fine details of the original silhouettes, therefore classification is based on the dimensions, line width and orientation of the objects.

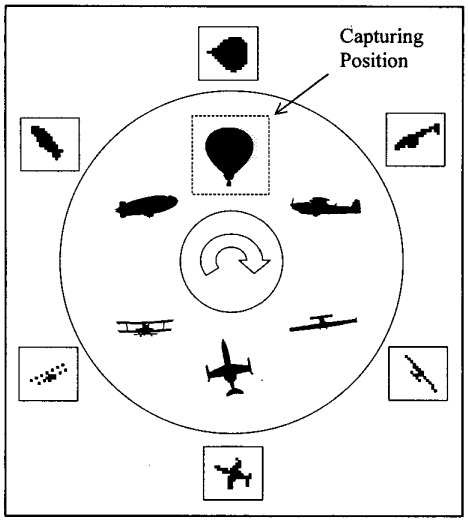

Figure 2. *Silhouettes of six different flying objects (balloons and airplanes) printed on a ring, and their low resolution (20×22) representation on the CNNUM chip. The chip's position is fixed, the printed objects turn round on a turntable, therefore the objects are rotated on the captured images*

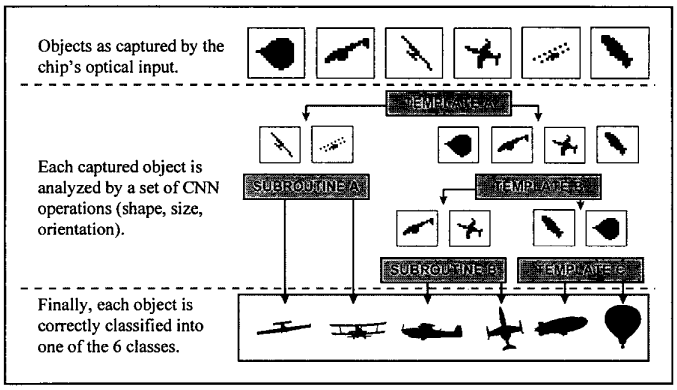

Figure 3. *Flowchart of the classification algorithm for six objects. Classification by a CNN template or subroutine means that for some input images the resulting image is empty, for others not. This can be detected by the global OR logic operation*

The whole classification process can be viewed in Figure 3. Each loaded image is processed by a number of CNN operations in order to classify objects correctly. In each cycle, the new input has to be loaded (optically), CNN template operations (on average: 4), local logic operations (4 in each cycle) have to be performed, and resulting images (on average: 3) have to be uploaded from the chip in order to evaluate them (global logic OR operation). In Figure 4 we list the execution times for each of these operations. A single image can be processed in 19,8μs, which results in more than 50,000 frames captured and processed in a second. This processing speed is far beyond the speed limits of digital signal processors.

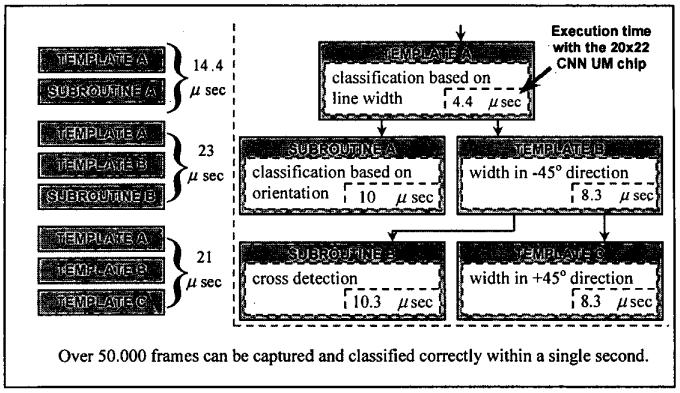

Figure 4. *Execution times of the CNN template operations required in the classification process. Overhead caused by result uploading and evaluation is included.*

4. Possible industrial applications

A large number of industrial applications are possible with this technology, and with the next generation of the CNN-UM chips which provide larger resolution, up to 128×128 or even 256×256. In this way the size of the captured and processed image is drastically increased, but the computational time is practically unchanged. They can be used in quality control in textile factories, visual robot arm control, part positioning in SMD mounting, etc. On the other hand, it can be used in those areas, where image processing was never used before. For example in agriculture or food industry no one thought before of visually inspecting all grain of rice or wheat from a field.

5. Conclusion

Ultra high frame rate image processing can be achieved by using the CNN-UM chips as focal plane array processors. With an optimal hardware, 50,000 frames can be processed in a second. With our general purpose test and measurement system we were able to go above 10,000 fps in complex decision tasks.

6. Acknowledgement

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