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Applying a Heterogeneous Parallel Algorithm to Estimate 3D Pose of Rigid Objects

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Introduction

Three-dimensional (3D) pose estimation is an important task for new engineering applications, such as augmented reality, driver-assistance, 3D reconstruction, image-guided surgery, and industrial metrology. An efficient pose recognition is complex to achieve due noise, occlusions, geometrical distortions, non-uniform illumination, and cluttered background. In this work we propose a heterogeneous parallel algorithm in a CPU/GPU architecture, in order to solve 3D pose estimation of rigid objects using correlation filtering techniques.

Pose estimation of rigid objects

A 3D pose estimation algorithm with a parallel approach using correlation filters is designed. Given an input image $f(\mathbf{x})$ and a digital 3D model of the target, the correlation process is carried out in order to find the best match. A bank of generalized matching filters is constructed, in which, each filter $H(\boldsymbol{\mu})$ represents a pose of the target according to a variation of 3D angles of orientation, location and scaling parameters. The filter is computed as follows:

$$H^*(\boldsymbol{\mu}) = \frac{2\pi(T(\boldsymbol{\mu}) + m_t W_b(\boldsymbol{\mu}) + m_t W_t(\boldsymbol{\mu}))}{|W(\boldsymbol{\mu})|^2 * N_b(\boldsymbol{\mu}) + |W(\boldsymbol{\mu})|^2 * N_t(\boldsymbol{\mu})}$$

where $T(\boldsymbol{\mu})$, $W_b(\boldsymbol{\mu})$, and $W_t(\boldsymbol{\mu})$ are the Fourier transform of the target, the inverse and direct support region, respectively. The terms m_t and m_b are the mean value of target and background. N_t and N_b are the spectral density function of target and background, respectively.

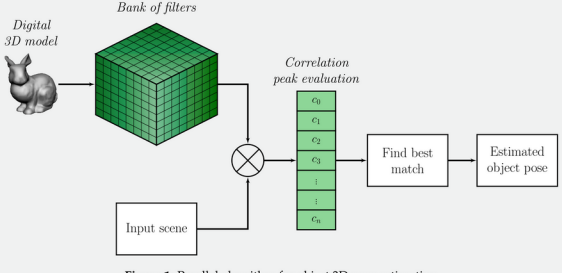

Figure 1: Parallel algorithm for object 3D pose estimation.

The output correlation function is given by $c_i(\mathbf{x}) = f(\mathbf{x}) \otimes \text{IFT}\{H_i^*(\boldsymbol{\mu})\}$. The best match is determined by the maximum score from the output correlation planes. This score is measured by a discrimination capability (DC) metric computed as $DC = 1 - |c_b|^2/|c_t|^2$, where c_b and c_t are the maximum correlation value in background and target. Fig. 1 shows the proposed algorithm, in which a bank of filters is designed using a known digital 3D at different poses [1].

[1] K. Picos, V. H. Diaz-Ramirez, V. Kober, A. S. Montemayor, J. J. Pantrigo. Accurate three-dimensional pose recognition from monocular images using template matched filtering. Opt. Eng., 55(6):063102, 2016.

Experimental results

Figure 2: Pose estimation of a rigid object on a CPU/GPU architecture.

Fig. 2 shows the performance of 3D pose estimation from an input scene in a cluttered background, where the entire filter bank is evaluated in order to find the best match. We propose a heterogeneous parallel algorithm on a CPU/GPU architecture. The program was coded in CUDA using OpenGL interoperability for 3D graphics visualization. Also we implement CPU thread parallelization using OpenMP. First, a set of templates are generated in OpenGL, in which the surface material is rendered with Phong-Gourad lighting model. These templates are scaled, stored and used for a parallel filter design in frequency domain using CUFFT API. The number of filters used in the bank are distributed between the available threads from CPU and GPU. Then, the algorithm is able to compute a massive correlation processes concurrently. A parallel evaluation of each correlation output is measured by DC metric. Finally the best match is computed in CPU in order to estimate an accurate 3D pose. Fig. 3 illustrates the execution performance of the algorithm using different configurations of the parallel architecture.

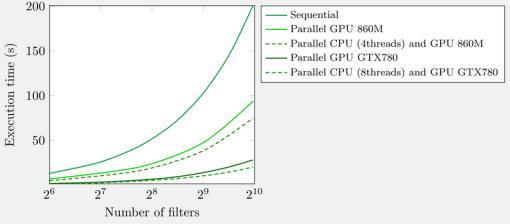

Figure 3: Execution performance with different heterogeneous parallel architectures.

Conclusions

This work presents an accurate 3D pose estimation of rigid objects using heterogeneous parallel computation. The proposed implementation processes a massive concurrent correlation operations in frequency domain. The parallel algorithm achieves almost 10× of speedup from the sequential execution. The proposed algorithm improves significantly the execution time.