

# GPU Implementations of HOG-based Object Detection using Deformable Part Models

Manato Hirabayashi, Shinpei Kato, Masato Edahiro  
Dept. of Information Engineering  
Nagoya University

Kazuya Takeda  
Dept. of Media Science  
Nagoya University

Seiichi Mita  
Research Center for Smart Vehicles  
Toyota Technological Institute

Vision-based object detection using camera sensors is an essential piece of perception for autonomous vehicles. Various combinations of features and models can be applied to increase the quality and speed of object detection. A well-known approach uses histograms of oriented gradients (HOG) with deformable models to detect a car in an image. A major challenge of this approach can be found in computational cost introducing a real-time constraint problem in the real world. In this paper, we present an implementation technique using graphics processing units (GPUs) to accelerate computations of scoring similarity of the input image and the pre-defined models. Our implementation considers not only the algorithm part but also the entire program structure for practical use. We also apply the presented technique for the real-world car detection program and demonstrate that our implementation using commodity GPUs can achieve speedups of 1.5x to 3x in frame-rate over sequential and multithreaded implementations using traditional CPUs.

**Index Terms**—GPGPU; Computer Vision; Object Detection

## I. INTRODUCTION

Grand challenges of cyber-physical systems (CPS) include a high computational cost of understanding the physical world. Object detection is one of compute-intensive tasks for CPS. For example, an autonomous vehicle needs to detect and track other vehicles by itself. Current autonomous driving technologies [6], [11], [16] tend to rely on active sensors such as GPS, RADAR, and LIDAR [9], [14] together with very accurate pre-configured maps, but the use of passive camera sensors is becoming more practical due to recent advances in computer vision [2]–[4]: vision-based object detection can be applied for various ranges and orientations. In particular, histograms of oriented gradients (HOG) [2] features provide reliable high-level representations of an image underlying many state-of-the-art object detection algorithms [3], [5], [13], [15], [17]. However, a major concern of HOG-based object detection remains in computational cost.

Previous work on the implementation of HOG-based object detection are limited to either hardware implementations [7], [8], [10] or specific parts of HOG algorithms [1], [12]. There is even no quantitative investigation of what implementation issues could prevent HOG-based object detection from being deployed in real-world applications. Given recent innovations in commodity hardware technology such as multicores and

graphics processing units (GPUs), it is worth exploring if the current state of the arts meets computational requirements of cutting-edge object detection implementations.

**Contribution:** This paper presents GPU implementations of HOG-based object detection in consideration of real-world applications using deformable part models [3]. While this is a popular vision-based object detection approach, what remains an open question is a generalized programming technique and a quantification of performance characteristics for practical use. We begin with an analysis of traditional CPU implementations to find fundamental performance bottlenecks of HOG-based object detection. This analysis reasons about our approach to GPU implementations where we parallelize compute-intensive blocks of the object detection program using the GPU step by step to minimize its makespan. The experimental results obtained from a real-world car detection program using a commodity GPU show that the GPU outperforms the CPU by 1.5x to 3x in frame-rate, while another 2x improvement would be needed at least to deploy in the real world.

**Organization:** The rest of this paper is organized as follows. Section II describes the assumption behind this paper. Section III presents an analysis of HOG-based object detection and our GPU implementation technique. Section IV evaluates the performance benefit of our technique over traditional CPU implementations. This paper concludes in Section V.

## II. ASSUMPTION

## III. GPU IMPLEMENTATION

### A. Analysis

### B. Approach

### C. Programming

## IV. EVALUATION

## V. CONCLUSION

## REFERENCES

- [1] Y-P. Chen, S-Z. Li, and X-M. Lin. Fast HOG Feature Computation based on CUDA. In *Proc. of the IEEE International Conference on Computer Science and Automation Engineering*, pages 748–751, 2011.
- [2] N. Dalal and B. Triggs. Histograms of Oriented Gradients for Human Detection. In *Proc. of the IEEE Conference on Compute Vision and Pattern Recognition*, pages 886–893, 2005.
- [3] P. Felzenszwalb, R. Girshick, D. McAllester, and D. Ramanan. Object Detection with Discriminatively Trained Part Based Models. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 32(9):1627–1645, 2010.

- [4] P. Felzenszwalb and D. Huttenlocher. Pictorial Structures for Object Recognition. *International Journal of Computer Vision*, 61(1), 2005.
- [5] A. Geiger, P. Lenz, and R. Urtasun. Are we ready for Autonomous Driving? The KITTI Vision Benchmark Suite. In *Proc. of the IEEE Conference on Compute Vision and Pattern Recognition*, pages 3354–3361, 2012.
- [6] E. Guizzo11. How Google’s Self-Driving Car Works. *IEEE Spectrum*, 2011.
- [7] R. Kadota, H. Sugano, M. Hiromoto, H. Ochi, R. Miyamoto, and Y. Nakamura. Hardware Architecture for HOG Feature Extraction. In *Proc. of the International Conference on Intelligent Information Hiding and Multimedia Signal Processing*, pages 1330–1333, 2009.
- [8] F. Karakaya, H. Altun, and V. Cavuslu. Implementation of HOG algorithm for real time object recognition applications on FPGA based embedded system. In *Proc. of the IEEE Signal Processing and Communications Applications Conference*, pages 508–511, 2009.
- [9] A. Kirchner and C. Ameling. Integrated Obstacle and Road Tracking using a Laser Scanner. In *Proc. of the IEEE Intelligent Vehicles Symposium*, pages 675–681, 2000.
- [10] M. Komorkiewicz, M. Kluczewski, and M. Gorgon. Floating Point HOG Implementation for Real-Time Multiple Object Detection. In *Proc. of the International Conference on Field Programmable Logic and Applications*, pages 711–714, 2012.
- [11] J. Levinson, J. Askeland, J. Becker, J. Dolson, D. Held, S. Kammel, J.Z. Kolter, D. Langer, O. Pink, V. Pratt, M. Sokolsky, G. Stanek, D. Stavens, A. Teichman, M. Werling, and S. Thrun. Towards Fully Autonomous Driving: Systems and Algorithms. In *Proc. of the IEEE Intelligent Vehicles Symposium*, pages 163–168, 2011.
- [12] V. Prisacariu and I. Reid. fastHOG – a Real-Time GPU Implementation of HOG. Technical Report 2310/09, Department of Engineering Science, University of Oxford, 2009.
- [13] P. Rybski, D. Huber, D. Morris, and R. Hoffman. Visual Classification of Coarse Vehicle Orientation using Histogram of Oriented Gradients Features. In *Proc. of the IEEE Intelligent Vehicles Symposium*, pages 921–928, 2010.
- [14] D. Streller, K. Furstenberg, and K. Dietmayer. Vehicle and Object Models for Robust Tracking in Traffic Scenes using Laser Range Images. In *Proc. of the IEEE International Conference on Intelligent Transportation Systems*, pages 118–123, 2002.
- [15] F. Suard, A. Rakotomamonjy, A. Bensrhair, and A. Broggi. Pedestrian Detection using Infrared Images and Histograms of Oriented Gradients. In *Proc. of the IEEE Intelligent Vehicles Symposium*, pages 206–212, 2006.
- [16] C. Urmson, J. Anhalt, H. Bae, D. Bagnell, C. Baker, R. Bittner, T. Brown, M. Clark, M. Darms, D. Demitrish, J. Dolan, D. Duggins, D. Ferguson, T. Galatali, C. Geyer, M. Gittleman, S. Harbaugh, M. Hebert, T. Howard, S. Kolski, M. Likhachev, B. Litkouhi, A. Kelly, M. McNaughton, N. Miller, J. Nickolaou, K. Peterson, B. Pilnick, R. Rajkumar, P. Rybski, V. Sadekar, B. Salesky, Y-W. Seo, S. Singh, J. Snider, J. Struble, A. Stentz, M. Taylor, W. Whittaker, Z. Wolkowicki, W. Zhang, and J. Zigar. Autonomous Driving in Urban Environments: Boss and the Urban Challenge. *Journal of Field Robotics*, 25(8):425–466, 2008.
- [17] Q. Zhu, M-C. Yeh, K-T. Cheng, and S. Avidan. Histograms of Oriented Gradients for Human Detection. In *Proc. of the IEEE Conference on Compute Vision and Pattern Recognition*, pages 1491–1498, 2006.