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主　論　文　の　要　旨

論文題目　A Decentralized Vision-based Perception System using GPUs and High Definition Map Features
（GPU 及び高精度地図を用いた画像ベース分散認知システム）

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論 文 内 容 の 要 旨

Autonomous driving systems have garnered extensive attention as a promising solution to various problems associated with transportation. To realize *high-level* autonomous driving systems, large volumes of data must be processed from external sensors with minimal delays to semantically perceive the surroundings and circumstances of ego vehicles. Tasks that involve data parallelism are often managed using graphics processing units (GPUs) to accelerate computation using a technique known as “general-purpose computing on GPUs.” However, whether a task can be accelerated using GPUs is case specific. Moreover, in the actual deployment of on-board autonomous driving systems, one must consider not only delays but also concerns such as precision and severe power limitations.

The primary objective of this study is the exploration of methods to accelerate perception tasks while fulfilling the criteria required for autonomous driving systems. Hence, the validity of GPUs as acceleration units for the perception tasks of autonomous driving systems are confirmed using two concrete examples. Subsequently, some concerns regarding the application of GPUs to on-board autonomous driving systems are considered, and a possible solution model is proposed. Thereafter, a performance analysis of a prototype model is presented to clarify the benefits of decentralized processing, followed by a summary of the conclusions. In this study, three concrete topics are addressed regarding perception tasks that use GPUs: (1) traditional image-based object detection, (2) traffic-light-state recognition, and (3) presentation of a decentralized processing model as well as performance analysis of its prototype.

After providing an introduction and a discussion of related studies, the application of GPUs for accelerating traditional pattern recognition tasks is presented herein. In this study, traditional image-based object detection tasks are considered. Because

advanced driver-assistance systems, which are widely implemented in many commercial vehicles, are typically based on traditional pattern recognition techniques, the approaches for these traditional techniques are expected to provide insights into the development of autonomous driving systems. A detailed workflow of the object detection algorithms is presented, with emphasis on how each component can be accelerated using GPUs. Subsequently, evaluation results are provided to quantify the performance improvements achieved via GPU-based implementations. Based on a detailed analysis of the workflow, it was discovered that approximately 98 % of the entire computation exhibits properties that have a high affinity for acceleration by GPUs. In the best scenario of GPU implementation, a performance improvement of 8.6× was achieved compared with a high-end central processing unit implementation, without changes to the algorithm flow. Subsequently, the current mainstream image-based object detection and traditional methods are compared. Based on the comparison, it is concluded that applying the mainstream approach is inevitable for implementing the perception modules of high-level autonomous driving systems.

Thereafter, a scheme to recognize traffic light states from images is reviewed to verify the practical application of GPUs to perception tasks. Because autonomous self-driving vehicles are expected to share roads with vehicles driven by people during the transition period for their introduction, autonomous vehicles must be able to recognize a wide range of traffic information, such as road signs and traffic lights. The proposed scheme for traffic-light-state recognition comprises two main parts: (i) utilizing ego-vehicle locations on high-definition three-dimensional maps to extract regions of traffic lights from images; (ii) utilizing a deep-learning-based recognizer that requires GPU acceleration. Using practical datasets obtained from public driving experiments, the proposed scheme yielded an average precision exceeding 97 % under favorable conditions. Moreover, if the recognition targets were within a distance of 90 m, then a recognition recall of approximately 90 % was achieved.

Possible concerns that may arise when applying GPUs to on-board autonomous driving systems are also discussed. As a countermeasure to these concerns, a model of a decentralized processing system using embedded-oriented GPUs as decentralized units is presented. To confirm the validity of the proposed model, a prototype is implemented for image-based object detection, and its performance analysis is discussed. The quantitative evaluations show that an approximate delay of 27 ms on average occurred between feeding an image to the system and receiving the object detection results by the host. This indicates that although the measured delay includes overhead from decentralized processing, frame dropping did not occur under the experimental setup conditions. Moreover, the proposed model degraded the network load of the host by several orders of magnitude, indicating its robustness against system scaling. Based on quantitative evaluations, it is concluded that autonomous driving systems can benefit from the proposed decentralized processing scheme, even with delays involved.