Hardware Software Co-Design for Autonomous Driving

In the following block diagram is presented a proposed block diagram to integrate the software stack for autonomous driving into the central hardware compute platform. As it is depicted, there are four different layers: application layer, runtime layer, operating system layer, and compute platform layer. The proposed stack represents a centralized computing platform, which integrates the input data from all sensors through a sensor fusion engine.

The basic functioning of this hardware and software stack begins with the hardware compute layer. This layer is based on System-on-Chip (SoC) architecture composed by an Input/Output subsystem which acquires data directly from the front-end sensors such as RADAR, LIDAR, and video cameras. When the sensors data is fetched into the shared memory, then ASICs, based on DSPs, are employed to preprocess the raw data from the sensors and extract features about the image stream. The GPU performs object recognition using deep learning frameworks. Since all the operation don't take place at the same time since the object tracking task is triggered once the object recognition task is accomplished, for instance, the FPGA is used to reconfigure the SoC during runtime using partial-reconfiguration techniques. It executes some data compression, data uploading, object tracking, and traffic prediction task. Finally, a multi-core CPU is currently employed for planning, control, and interaction between sensors through the operating system.

On top of the hardware compute layer, the runtime layer is in charge of mapping data workloads to the hardware components through OpenCL, and to schedule tasks through a runtime execution engine for the execution of the vehicles functions. In the operating system layer, we find the Robot Operating System (ROS), which splits high level tasks in low level task. It employs nodes, which are processes that perform computation, to transfer data between tasks over an abstraction called topics. If the image recognition task requires images from the camera sensor, then the OS publishes a topic to send messages from the camera to the image recognition module, and at the same time it subscribe a topic to make that the image recognition ready to receive the images.

<table>
<tr><td>Application Layer</td><td>Sensing</td><td>Perception</td><td>Decision</td><td>Planning</td><td colspan="2">Control</td></tr>
<tr><td>Operating System Layer</td><td colspan="6">ROS Node</td></tr>
<tr><td rowspan="2">Runtime Layer</td><td colspan="6">Execution Runtime</td></tr>
<tr><td colspan="6">Open CL</td></tr>
<tr><td rowspan="3">Hardware Compute Layer</td><td colspan="3" rowspan="3">Input/Output Subsystem</td><td colspan="3">CPU computing</td></tr>
<tr><td colspan="3">Shared Memory</td></tr>
<tr><td>ASIC</td><td>GPU</td><td>FPGA</td></tr>
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Internal communication, port and interfaces

Although there are other communication interfaces such as CAN, Ethernet is the technology to achieve the deployment of autonomous driving since it supports a higher number of devices that can be connected to the internal car's network, while enabling higher data rates. The hardware inside the vehicle such as sensors and computers require high bandwidths to transfer massive quantities of data.

Current radar and video sensors produces data at a rate of 100Mbyte/s each. Nowadays, the cars under development of the level 4/5 for autonomous driving dispose of 10 to 20 sensors. Then, internal car network needs to transport raw data at a rate of 2GByte/s. Additionally, the telematics module, which is in charge of connecting the car to other cars, the infrastructure, and the cloud, requires an additional data rate of 1GByte/s.

Apart from the merely communication, the internal data storage system must be selected to support high data volumes at high data transfer rates and. Therefore, the internal data storage system must support RAID systems that can be coupled with multiple and independent hard disks to form a disk network. In the following block diagram is clarified how is the interconnection between different internal communication modules and the data storage system. The communication between the Vision and Sensor Fusion SoC and the decision engine, and the communication between the telematics module and the decision engine, are controlled by the Ethernet interface. The memory interface of the Fusion sensor is 32 bits wide, while in the telematics module can vary from 16 to 32 bits wide. The NOR flash memories are used for functional safety compliance .