CHAPTER IX. COMPUTING HARDWARE AND EQUIPMENT

IX.A. Discussion

Teams which participated in the 2005 GCE completed 48.3 miles of the 2005 GCE course, on average, and teams which participated in the 2004 GCE completed 1.95 miles of the 2004 GCE course, on average. Based on the increase in the number of miles of the 2005 GCE course completed, the author proposed an increase in processing power available to the controlling intelligence was a key factor.

To determine if there was an increase in processing power between the 2004 and 2005 GCE the author reviewed 2004 and 2005 technical proposals and concluded insufficient technical detail was reported to determine the quantity, manufacturer, and model number of computing hardware and equipment in use by the teams. The author concluded that meaningful comparison between the computing hardware and equipment in use by the teams which participated in the 2004 QID and GCE and 2005 GCE using existing benchmarks would not be productive.

IX.B. Analysis

However, the author reviewed the published record and evaluated the computing hardware and equipment in use by teams which participated in both the 2004 and 2005 GCE to determine if there was an increase in the number of computers or an increase in the number of processors.

- Teams 2004-02 and 2005-01

Team 2004-02 stated: “The Challenge Vehicle will utilize five (5) shock-mounted Pentium class servers and one (1) National Instruments Compact Field Point system. Four of the five servers are motherboard-based 19” rack-mounted computers, 2 server-unit (2U) form-factor in height. The fifth server is a Dell Optiplex, standard desktop PC.” ([9], p. 5).

Team 2005-01 stated: “[The challenge vehicle] utilizes five (5) shock-mounted Pentium class servers and one (1) National Instruments Compact Field Point system. The five servers are motherboard-based 19” rack-mounted computers, 2 server-unit (2U) form-factor in height.” ([10], p. 4).

The author concluded there was no increase in processing power.

Teams 2004-02 and 2005-01 reported sufficient technical detail to determine the quantity, manufacturer, and model number of computing hardware and equipment in use by the team.

• Teams 2004-04 and 2005-02

Team 2004-04 stated: "[The challenge vehicle] uses a network of four single board computers, a PhyCore MPC565 PowerPC microcontroller, a military ruggedized Itronix GoBook II notebook computer, and a D.Module.C6713 Digital Signal Processor (DSP) to distribute the processing and intelligence required for the Grand Challenge." ([44], p. 3).

Team 2005-02 stated ([167], pp. 5 - 6):

> The high level computational needs are met in the deployed system via the utilization of single processor computing nodes targeted at individual computational needs...
>
> The individual computing node hardware architecture was selected based on the subjective evaluation of commercial off-the-shelf hardware. Evaluation criteria were centered on performance and power consumption. The deployed system maintains a homogenous hardware solution with respect to motherboard, ram, enclosure, and system storage. A processor family was selected based on power consumption measurement and performance to allow tailoring based on performance requirements with the objective of power requirement reduction. Currently three processor speeds are deployed.

Team 2005-02 later stated ([50], pp. 604 - 605):

> The high-level computational needs are met in the deployed system via the utilization of eight single-processor computing nodes targeted at individual computational needs...
>
> The individual computing node hardware architecture was selected based on the subjective evaluation of commercial off-the-shelf hardware. Evaluation criteria were centered on performance and power consumption. The deployed system maintains a homogenous hardware solution with respect to the motherboard, random access memory (RAM), enclosure, and system storage. The AMD K8 64-bit microprocessor family was selected based on power consumption measurement and performance to allow tailoring based on performance requirements with the objective of

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power requirement reduction.  Currently, three
processor speeds are deployed: 2.0 GHz, 2.2 GHz, and
2.4 GHz.  The processors are hosted in off-the-shelf
motherboards and utilize solid-state flash cards for
booting and long-term storage.  Each processing node
is equipped with 512 to 1028 MB of RAM.
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The author concluded there was an increase in processing power.

- Teams 2004-06 and 2005-03

Team 2004-06 reported an unknown number of "TI TMS2406" processors, one "TMS2407 class DSP", and three "TI TMS6414 processors running at 1 Ghz each" were in use by the team ([114], pp. 1 - 2).

Team 2005-03 stated: "The entire camera and navigation system is enabled by the use of 10 embedded TI C6416 DSP processors running assembly code." ([33], p. 3).

The author concluded there was an increase in processing power.

- Teams 2004-07 and 2005-05

Team 2004-07 stated: "Two 1.5-GHz Intel processors will be used for vision processing tasks while a third is used to calculate obstacle-free trajectories, and a fourth will do state estimation based on input from the GPS, compass, and vehicle speed sensor, and send control signals to the steering, accelerator, and brake actuators to keep the vehicle on the target trajectory. One 1-GHz EPIA M-10000 VIA processor handles information from the radar." ([46], p. 3).

Team 2005-05 stated: "Our experience has generally been that we are not processor-limited and that a single laptop computer is sufficient to do all the tasks of processing laser range data, planning trajectories, and controlling the vehicle. The important exception is computer vision which does tend to be processing-intensive and is performed on its own processor, either another laptop or custom hardware such as the single board computer, based on a single Motorola PowerPC 7410 (G4) processor, supplied by Mobileye LTD." ([34], p. 3).

Team 2005-05 later stated: "A second design aim was to keep the computational architecture as simple as possible. The core tasks of autonomous driving do not require a large amount of computational power. We worked to keep the software running on a single laptop computer. Unburdened by a rack full of computers, we were able to retain working space in the vehicle, but more importantly, any team member could plug in their laptop with a universal serial bus (USB) cable and run the vehicle." ([170], p. 529).

The author concluded there was a significant decrease in processing power.

Teams 2004-07 and 2005-05 was the only team which reported a decrease or significant decrease in processing power between the 2004 and 2005 GCE.

- Teams 2004-08 and 2005-07

Team 2004-08 stated: “The computing systems involved in our design require the use of 5 computers.” ([76], p. 3), but reported no additional identifying information for the computers in use by the team.

The Team 2005-07 technical proposal was unavailable for review and Team 2005-07 did not publish its results via the Journal of Field Robotics. See paragraph V.C.32. Available published records ([233] and [118]) did not report the computing hardware and equipment in use by Team 2005-07.

The author concluded insufficient technical detail was reported to determine if there was an increase in processing power between the 2004 and 2005 GCE.

- Teams 2004-10 and 2005-13

Team 2004-10 reported “Pentium III PC104 Stacks”, one “Itanium 2 Based Server, 4 Processors”, and one “Xeon Based Computer, Dual processors” were in use by the team ([77], p. 3). Team 2005-13 reported four “Pentium III PC104 stacks” and seven “Pentium M Compact PCI computers” were in use by the team ([11], p. 4).

The author concluded there was an increase in processing power.

- Teams 2004-13 and 2005-15

Team 2004-13 stated: “Here is a list of the computers and their module assignment: Vehicle control: embedded computer or ruggedized laptop. Obstacle and environmental sensing: rugged PC with PCI interface card. Road / path finding: ruggedized laptop, firewire frame grabber and PCMCIA interface. Path planning: ruggedized laptop. [Challenge vehicle controlling intelligence]: ruggedized laptop. A number of simple microcontrollers will be used to interface the computers to sensors and actuators.” ([232], p. 2).

Team 2005-15 stated: “We use two 750 MHz Pentium-4 embedded systems built as a PC104+ stack.” ([53], p. 6).

Team 2004-13 did not report the number of computers in use by the team. As a result, the author was unable to determine if multiple modules shared a single computer, for example if modules “Vehicle control”, “Road / path finding”, and “[Challenge vehicle] Brain” shared a single “ruggedized laptop”, or if each was assigned to an individual laptop. In addition, Team 2004-13 stated module “Vehicle control” was assigned to an “embedded computer *or* ruggedized laptop” (*emphasis added*). As a result, the author concluded Team 2004-13 had not determined how many computers were in use by the team at the time the team technical proposal was submitted for review. The Team 2004-13 technical proposal is undated.

The author concluded insufficient technical detail was reported by Team 2004-13 to determine if there was an increase in available processing power between the 2004 and 2005 GCE.

- Teams 2004-16 and 2005-17

Team 2004-16 reported “Two ATHLON Pc’s” were in use by the team ([138], p. 3).

Team 2005-17 stated: “A single, garden variety mother board is replaced by two Dell Power Edge 750 computers and two mini-ITX boards.” ([140], p. 2).

Team 2005-17 later stated: “The computing system... provides the computational power of [the challenge vehicle]. The computers labeled 'Main Machine' and 'Extra Machine' are Dell PowerEdge 750s... The other two computers 'NTP Machine' and 'Disk Logger Machine' are mini-ITX boards...” ([196], p. 560).

Regardless of whether a “single, garden variety mother board” or “Two ATHLON Pc's” were in use by Team 2004-16, the author concluded there was a significant increase in processing power.

- Teams 2004-17 and 2005-18

Team 2004-17 stated: “The Challenge Vehicle will contain up to 9 regular desktop, IBM, Pentium 4, 3.0Ghz PC computers and an IBM laptop.” ([142], p. 5).

Team 2005-18 stated: “[The challenge vehicle's] software systems run on six Dell PowerEdge servers and two quad-core IBM Opteron-based servers...” ([197], p. 7).

Team 2005-18 later stated: “The computing platform consists of six Dell PowerEdge 750 servers with 3 GHz, Pentium 4 processors and a single IBM eServer 326 with dual 2.2 GHz dual-core AMD 64 processors.” ([54], p. 781).

Although Team 2004-17 did not report the number of computers in use by the team, but stated the challenge vehicle will contain “*up to* 9 regular desktop” (*emphasis added*) computers, the author concluded there was an increase in processing power.

- Teams 2004-18 and 2005-20

Team 2004-18 stated: “Three computers have been implemented [*sic*] One computer handles the environment sensing, while the second computer handles the map matching and path logic, and the third computer handles vehicle control and system feedback. Two of the computers are 1.6 GHzGETAC [*sic*] Laptops with custom power, data acquisition cards, and filters. The control computer consists of a 1.3 GHz processor running a real-time operating system, as well as a motor controller and digital and analog interface cards. This computer is a PXI (PCI extensions for Instrumentation) form factor." ([48], pp. 2 - 3).

Team 2005-20 stated: "The computational hardware consists of seven computers including a National Instruments PXI, a National Instruments CompactRIO, four MINI ITX Pentium 4 computers, and a single Pentium 4 extreme edition 3.73 GHz computer that uses hyperthread technology for the stereo camera." ([56], p. 4).

The author concluded there was a significant increase in processing power.

- Teams 2004-23 and 2005-21

Team 2004-23 reported six "Pentium 4 machines" were in use by the team ([159], p. 3).

Team 2005-21 did not report the computing hardware and equipment in use by the team via the team technical proposal ([160]).

Team 2005-21 later stated: "The autonomous system consists of computers, communication network, sensors, vehicle control interface, and the supporting mounting and protection structures. The autonomous system utilized in the 2004 DGC was completely removed and upgraded for the 2005 DGC." ([57], p. 694).

The author concluded there was an increase in processing power.

- Teams 2004-25 and 2005-22

Team 2004-25 stated: "The computing systems for the Challenge Vehicle consist of four sensor interface computers, a global mapping computer, a local mapping/path-planning computer, and a system status/motion control computer." ([49], p. 4) and "The Challenge Vehicle uses three National Instruments Compact Field Point (cFP) 2010 units and a CVS-1454 Compact Vision System to capture and preprocess local sensor data." ([49], p. 6). Team 2004-25 reported one "PXI – 8176 Controller", one "PXI 8186 Controller", and one "PXI-8174 Controller" were in use by the team.

Team 2005-22 stated: "Computational power on [the challenge vehicle] is distributed across three National Instruments PXI-8176 controllers." ([58], p. 2).

Team 2005-22 later stated ([59], p. 711):

> Both vehicles are equipped with National Instruments PXI-8176 controllers. These controllers are high-performance compact personal computers containing Pentium processors with up to 1 GB of random access

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memory.  The controllers can run at speeds ranging
from 1.2 to 2.6 GHz...

The three computers on [the challenge vehicle] each
perform a specific task: Vision, INS/Path Planning,
and Motion Control.
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The author concluded there was an increase in processing power.

Teams 2004-25 and 2005-22 reported sufficient technical detail to determine the quantity, manufacturer, and model number of computing hardware and equipment in use by the team.

IX.C. Results

Of teams participating in both the 2004 and 2005 GCE:

- Two of 12 teams (17 percent) reported sufficient technical detail to determine the quantity, manufacturer, and model number of computing hardware and equipment in use by the team.
- There was an increase or significant increase in processing power available to the challenge vehicle controlling intelligence for eight of 12 teams (67 percent).
- There was no change in processing power available to one of 12 teams (eight percent).
- There was a decrease or significant decrease in processing power available to one of 12 teams (eight percent).
- Insufficient technical detail was reported to determine if there was an increase in processing power available to the challenge vehicle controlling intelligence for two of 12 teams (17 percent).

IX.D. Conclusions

Teams which participated in the 2005 GCE completed 48.3 miles of the 2005 GCE course, on average. Teams which participated in both the 2004 and 2005 GCE completed 48.6 miles of the 2005 GCE course, on average. Teams which participated in the 2005 GCE but not the 2004 GCE completed 47.9 miles of the 2005 GCE course, on average. See paragraph X.D.1.

As a result, although there was an increase or significant increase in processing power available to the challenge vehicle controlling intelligence for 67 percent of teams which participated in both the 2004 and 2005 GCE, the author was unable to conclude teams which participated in both the 2004 and 2005 GCE completed more miles of the

2005 GCE course as a result of an increase in processing power than teams which participated in the 2005 GCE but not the 2004 GCE. In addition, teams which participated in the 2005 GCE but not the 2004 GCE provide no basis for comparison, and insufficient technical detail was reported to determine the quantity, manufacturer, and model number of computing hardware and equipment in use by the vast majority of teams which participated in the 2004 QID or GCE or 2005 GCE.

However, the fact remains that teams which participated in the 2005 GCE completed 48.3 miles of the 2005 GCE course, on average, and teams which participated in the 2004 GCE completed 1.95 miles of the 2004 GCE course, on average. The author concluded corporate and academic sponsorship allowed teams which participated in the 2005 GCE but not the 2004 GCE to effectively "buy in", by providing access to resources such as labor, high-quality sensors, and computing equipment, and COTS technologies such as integrated challenge vehicle controls and COTS components used to integrate navigation sensors. See paragraph X.D.2. The author proposes this may have enabled these teams to participate in the 2005 GCE on a more even basis with teams which participated in both the 2004 and 2005 GCE, 67 percent of which increased or significantly increased the processing power available to the challenge vehicle controlling intelligence.

As a result, the author concluded an increase in processing power available to the challenge vehicle controlling intelligence was a key factor.

Ironically, following the unsuccessful conclusion of the 2004 GCE, DARPA stated: "Work in this area continues to address increasingly difficult route planning and terrain navigation challenges, but under the assumption Moore's law would enable higher vehicle speeds in the future." ([3], p. 2). Insufficient technical detail was reported to conclude the increase in available processing power between the 2004 and 2005 GCE observed by the author was a direct consequence of Moore's Law, but the increase in processing power available to the challenge vehicle controlling intelligence contributed to the higher vehicle speeds predicted. The author asserts the effect was indistinguishable from an increase in processing power due to Moore's Law.