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Parallel Computer Technology - A Solution for Automobiles?

How car engineers can learn from parallel computing

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Abstract—**This paper gives a short overview of the information technology in today's car electronics and software components, with main focus on the dramatically increasing intra-car-communication and the accumulative number of electronic control units due to the complexity of current new applications, e.g., the very new semi-autonomous car driving. It is shown how the car industry can learn from parallel computing technologies for succeeding their new upcoming challenges in the close future.**

Keywords - parallel computing; information technology; car electronics; automotive engineering; AUTOSAR.

I. INTRODUCTION

Since the 1980s, when the information technology came up to the car, the engineering process has turned from a pure domain of mechanics to a wide ranged crossover engineering of mechanics and electronics. During the years a lot of new functionalities were provided that no one wants to renounce today. Well known examples are the vehicle safety, air conditioning or car navigation systems. But this is not yet the end. The future will bring more and more intelligent applications in cars, as for example the very latest driver's assistance systems up to the autonomous car driving. The increasing complexity of these new applications will require new technologies in the close future. That's why the advances of the information technology will be a vital factor for the car industry in the next years.

In the following, this article shows the current state of the information technology in cars with its problems today. A future scenario, based on the today's technology, will be created. At the end, it will be discussed how the future scenarios could be improved by the adoption of well known parallel computing technologies.

II. HISTORY OF CAR ELECTRONICS

To get a better idea of the closer future, it is advised to look back first at the evolution of the car electronics in the past. The following Table I shows the history of the car-electronics since 1950 in note form. Firstly it can be noticed that the object of car engineering during all the years was extended from a pure mechanical construction into a wide mixture of mechanics and electronics. This consciousness will help to get an idea about the coming future. Secondly it can be observed that the distance between the dates becomes closer that means the evolution of the car-electronics became faster the last years.

TABLE I. HISTORY OF CAR ELECTRONICS 1950-2008

Year	Innovation
1950	Mercedes 170 V: the only electrical system components are a generator, battery, lamps, indicators and ignition. 40 single cables are sufficient for the whole vehicle.
1970	The first electronic ignition systems in standard vehicles.
1980	Firstly electric point-to-point connections are replaced by electronic control units and the CAN-field bus. The first electronic motor management system manufactured by BOSCH sets a new benchmark.
1990	Electronic control units for motor management and anti-lock braking systems are standard in all auto classes. Software starts to play a significant role in the car.
2000	The Mercedes S-class has built-in up to 80 control units. Vehicles of the luxury class begin to intend driver's assistance and information systems as for example distance radar or GPS navigation serially. Approx. 4 km of copper cable are necessary to couple all electronics components. Problems result by the costly wiring and the software interaction between electronic control units.
2004	ESP and air bag are standard in all classes. For vehicles like Audi A8, VW Phaeton, BMW 7th series and Mercedes S-class more and more complex driver's assistance and information systems are offered.
2007	Audi Q7 and Porsche Cayenne have reached 6 km cable length. For bandwidth reasons additional coaxial cables are integrated in the cable harness for cameras and head-up display.
2008	BMWs of the 7th series have up to 90 control units. A recentralization of the control units is intended, so that the number sinks back to approx. 60. Whereby the cable harness will be shorter and the costs for electronics and software sink.

Some points, which can be learned from the evolution of car electronics, are shown in Table I: (1) the number of electronic control units (ECUs) has risen rapidly the last years, (2) the data communication due to the number of networked ECUs plus their sensors and actuators has risen in the same way, (3) the time intervals became shorter, this means the evolution of car electronics became faster, (4) while the application software became more complex, (5) and finally, the technical innovations of the luxury class will be standard in all vehicles just a few years later.

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III. CURRENT STATE OF THE TECHNOLOGY

Since the introduction of the first electronic control units their number has been increased more and more. Almost every newly-created function led in another ECU. With the increasing number of ECUs the intra-car communication network is getting more and more complex. Even if the CAN bus [1] as the sole communication system in cars was sufficient for a very long time, due to new requirements other communication systems came up within the last years. Additionally to the CAN bus the specific bus systems MOST and FlexRay are present in the automobiles of today [2,3,4]. MOST (Media Oriented Systems Transport) was developed explicitly for multimedia and infotainment applications with higher data rates that CAN does not provide. FlexRay with its deterministic properties is made for real time and safety applications and deem to be a successor of CAN which has no real time capabilities. But first built-in in a standard vehicle in 2006 FlexRay is still in the minority.

Figure 1 shows exemplarily a communication network of ECUs in a standard vehicle with a CAN field bus plus the newer field bus systems MOST and FlexRay.

As shown in Figure 1 the architecture of today's car electronics is a car-wide distribution of electronic control units connected by field bus systems. The problem here: because of their very special properties all of these field bus systems are not compatible to each other. For example CAN is an event-triggered communication network while FlexRay provides a time-triggered communication. The coexistence of such different kinds of communication networks will work as long as ECUs can be linked based on their particular functional relationship as shown in Figure 1. But the interfacing of all different types of communication networks is quite not possible. In addition to the already existing field bus systems in cars, some newer design and development work goes to Industrial Ethernet and the IP-protocol used for an intra-car communication network [5].

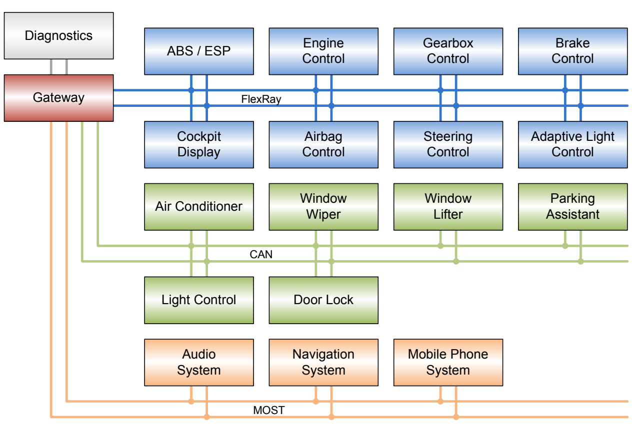

Figure 1. Communication network of a standard vehicle

But why do all these ECUs need to be linked as a whole? The reason is that the complexity of upcoming applications requires the interaction of all ECUs. While in the past every ECU was a discrete functioning module, in the future newer complex functions will require a data communication interlink of all ECUs in the whole wide car.

IV. WHAT IS THE FUTURE?

The complexity of the car-wide communication network as exemplarily seen in Figure 1 will increase continuously according to the Intelligent Car Initiative within the European strategy i2010 [6]. Several driver's assistance systems are already on production. There can be found assistants for parking (fully automatically parking is already available in today's standard vehicles), for distance control, lane keeping, emergency braking, etc. But with standing on the current technology the increasing complex functions may cause the following scenario as shown in Table II.

TABLE II. FUTURE SCENARIO WITH CURRENT TECHNOLOGY

Year	Innovation
2015	The driver's assistance systems e.g. for automatic lane holding, lane changing, convoy driving, parking, etc. get more currency. The car has turned into a mobile multi-computer system with a very complex, heavy and costly wiring up to a 10 km length.
2020	The automatic parking is in series production. On-board cameras are car standard. The required bandwidth can be allocated only by the use of LAN-technologies from the computer industry, as for example Gigabit Industrial Ethernet. All cable technologies are coexistent in the vehicle.
2030	Autonomous driving is ready for series production. The car is from the view of 2009 a mobile supercomputer driven by an electric drive on telematic controlled roads. Compact cable chutes cross the whole car and change the design and usable space in the car significantly.

The drafted scenario is the result of two conditions: (1) the car electronics is distributed to multiple control units, (2) various field bus technologies are used in the same car.

What can be learned from Table II in continuance of Table I: the high complexity of future car electronics is almost infeasible with the today's technology. Further technical progress will be essential within the coming years. The following main points will become necessary:

A. High software abstraction level

Looking to the currently used ECUs software closely written to the underlying hardware can be found. That means there is a very low level of hardware abstraction in the software. In case that the hardware will change, new application software has to be developed in consequence. Regarding to a wide variety of car models, a shortened car model life cycle plus the higher complexity of application software the current state will not be acceptable in future.

B. Software layer model

With the introducing of a layer model for software, the following could be reached: (1) according to point A the software abstraction level can be raised, (2) the application software can be developed independent from the later hardware, (3) variable hardware can be used for the same application software by the use of suitable middleware, (4) once tested and validated software can be reused.

C. *Homogenous communication network*

The increasing complexity of software applications in the car requires the interlinking of all ECUs in the whole car. To meet this requirement a homogeneous communication network instead of the various and incompatible field bus systems will be essential.

D. *Lower number of ECUs*

The high number of distributed ECUs in association with complex application software is a reason for the increasing intra-car data communication. There is no chance to simplify the application software, so reducing the number of single ECUs will be, amongst others, very important for the ability to reduce the very costly and heavy cable harness in the car.

V. What Car Engineers Can Learn from the Parallel Computing Technology

Most of the described points for the technical progress in car electronics are already covered by the introduction of the specification of AUTOSAR [7]. For example, with the implementation of AUTOSAR in the electronic control unit software, a software layer model with application software separated from hardware is done. This way AUTOSAR is an important first step ahead. But, nevertheless, two essential points are still open: (1) the homogeneous network and (2) the lower number of ECUs.

A. *Homogenous communication network*

The currently used communication networks in the vehicles of all classes today are the field bus systems CAN, LIN [8], MOST and FlexRay. In terms of the OSI 7 layer model the mentioned field bus systems are low level communication networks. For example, CAN (<1 Mbit/s) works only on layer 1 and 2a in the OSI 7 layer model for layered communication, it cares about bit transmission and access to the bus only. For higher functionalities special protocol software as for example CANOpen [9] was created which has to be installed in every control unit, but the abstraction level of a computer network was not reached. The real time network FlexRay (<10 Mbit/s) implements the layers 1-2a only. Missing functionality and low abstraction level for the data communication are managed by user application software in every control unit. With the multimedia network MOST (<150 Mbit/s) the network layers 1 and 2 cover the layer 3-7 completely more or less.

Why not using a communication network as already known from the interconnection network of a multi-computer? With a computer network instead of a field bus system higher data rates are possible with the complete abstraction level of all OSI 7 layers. Plus a computer network with real time capabilities is useful to connect the ECUs as well as all peripheral sensors and actuators. This way a homogeneous intra-car communication network with full capabilities is technically feasible.

B. *Recentralizing the electronic control units (ECUs)*

One of the reasons for the increasing data communication is the high number of interlinked ECUs due to the complexity of car application software. With lowering the number of ECUs the communication network can be simplified plus the car cable harness with it. But how this can be proceded?

First, as known from parallel computing, multiple processes are able to run parallel on a multi-computer system. With the specification of AUTOSAR the basics therefore already exist. Why? Because AUTOSAR specifies a software layer model that separates the application software from the hardware. The ECU application software is packed into small software modules, the AUTOSAR software components [7]. In addition all application software components are running in a defined Runtime Environment interlinked via a Virtual Functional Bus [7]. In fact, with building the Runtime Environment of AUTOSAR in a multi-computer system all application software of the car could be centralized in one single device instead of the car-wide distribution of ECUs. Thus the cable harness of the car could be reduced as well as the scalability could be improved.

Further the communication network of the multi-computer system could be the same as the peripheral communication network. In consequence there would be a homogenous communication network for the whole car. Plus the benefit that every application software process is able to communicate with every other application software process as well as with every sensor and every actuator.

The specification of AUTOSAR determines the following communication interfaces for application software components:

- Sender-Receiver Interface
- Client-Server Interface

For these communication interfaces of the AUTOSAR Runtime Environment the following well known methods of the parallel computing could be used: (1) message passing and (2) shared memory.

Message passing is used in parallel computing as an interprocess communication. The communication is made by the sending messages to recipients. The established Message Passing Interface (MPI) specifies the message passing as a language-independent communications protocol [10].

Shared memory is memory that may be simultaneously accessed by multiple programs. The intention of shared memory in parallel computing is to provide communication among multiple processes and to avoid redundant copies. For shared memory applications OpenMP could be used [11].

With both of these methods it should be possible to build a Virtual Functional Bus in a multi-computer system. If this is successful every part of the application software can be taken from the distributed ECUs, placed into a single device and run there.

VI. A Parallel Computer for Automobiles

In consequence of the idea to develop a parallel computer for automobiles the Clausthal University of Technology has started the project “ConPar”.

The parallel computer ConPar will have the following major tasks:

- Read-in and process sensor data
- Write output data on-line
- Real time process communication

A. Specification of ConPar

Typical applications of ConPar are characterized accordingly to the automotive requirements by hard real time properties and a high reliability. The sensor data plus the intermediate results have to be provided on every measuring cycle. Therefore it is imperative that the in- and outputs as well as the interprocess communication are in real time. The number of the attached sensors and actuators will be in a range of up to 1000. The single measuring signals are normally heterogeneous but they can be abstracted to homogeneous groups. For example the signal of a single tire sensor can be dedicated to the group of tire sensors.

The length of a measurement is supposed with typically 1-4 byte. The interprocess communication will be in a range of 4-128 byte. A measurement cycle (the time from one sample to the next sample) is in a range of 10ms to 100µs. The problem here is to meet the real time requirements all compute tasks have to be completed within one measurement cycle. In fact, every measurement cycle delivers approx. 100 Kbyte of data coming from cameras for parking, lane keeping, lane changing, etc. In consequence this will produce data traffic of 10 Mbyte/s up to 1 Gbyte/s!

B. I/O requirements

The specialty of an automobile computer is the ability to read actual conditions via sensors and to give any action via actuators. For this reason the parallel computer of ConPar will have a major focus to the in- and outputs:

- serve the sensors and actuators
- buffer measurements in FIFO until processing
- scale or conversion of measurement values
- process of conventional ECUs
- output of results

The communication with peripheral sensors and actuators is very special to ConPar. The interlinking of all components will be realized by “CarRing II”, a real time computer network [12]. This computer network is a result of research and development work for X-by-wire systems at the Department of Informatics of the Clausthal University.

C. Parallel computer requirements

The parallel computer of ConPar is designed to reduce the high number of ECUs by recentralizing the application software. ConPar will meet the following in consideration of the automotive special conditions:

- process of 32-128 parallel tasks in real time
- emulation of current automotive ECU software
- compute process data (use of control algorithm)
- image processing for camera data
- interprocess communication
- process redundancy for safety reasons

ConPar is able to handle multiple emulations at the same time, i.e. a support of Multiple Instruction Multiple Data (MIMD) mode is required. In addition, as described previously in example with tire sensors, measurement signals can be abstracted to homogeneous groups. The measurements of a homogeneous group are processed by the same algorithm as Single Instruction Multiple Data (SIMD) mode. Last but not least, the same measurements can also used for multiple algorithms at the same time. ConPar is operating in Multiple Instruction Single Data (MISD) mode.

D. Architecture of ConPar

To meet all the described requirements every single processor of the parallel computer will be allocated for a single process. Due to future applications and with the previously mentioned numbers, ConPar has a maximum of 256 processors. With using 16 core CPUs (available maybe in 2012) ConPar is a conglomerate of 16 CPUs. The inter-processor communication, the read-in of sensor data, and the output of actuator setpoints will be done by the known message passing and shared memory. Certainly because of latency reasons shared memory is preferred.

The hardware architecture of ConPar is geared to Amdahl's law:

- relation of communication bandwidth to processing power is approx. 2 byte/time division/FLOP
- relation of I/O bandwidth to processing power is approx. 1 bit/time division/FLOP
- relation of memory size to processing power is approx. 1 byte/FLOP

For reasons of economy standard computer components will be used. Notebook motherboards will provide the CPUs, communication nodes are made with FPGAs. In the future all the used hardware components are able to be replaced by compatible succeeding models which are cheaper, faster, and more efficient. The development software bases on either an open source distribution of Linux or Windows (GNU GCC, MS Visual Studio).

The communication between the CPUs plus the peripheral sensors and actuators shall be realized with CarRing II. With the implementation of all communication layers of CarRing II in Virtex-4 FPGAs the data communication will be fully accelerated by hardware with maximum speed. On Layer 1 of the OSI layer model CarRing II uses the communication port “Rocket I/O” from Xilinx. Rocket I/O achieves a maximum bit transfer rate of 6 Gbit/s per channel. In addition, CarRing II owns a deterministic real time property with message prioritization. This way CarRing II is able to guarantee a determined delivery time for data packages.

The coupling of the compute nodes is made by a communication network in form of a three dimensional torus. Therefore, the ring topology of CarRing II is used with rings in x-, y- and z-direction. Every communication node owns three communication rings for one ring in each direction. The communication network topology of ConPar is shown in Figure 2.

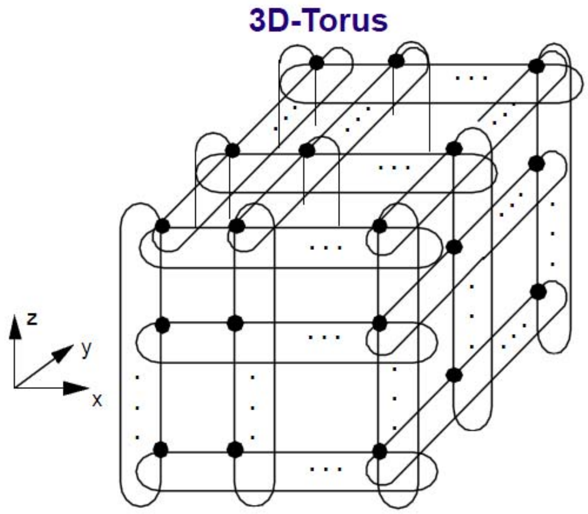

Figure 2. Communication network topology of ConPar

In maximum extension the 3-D torus has a dimension of four 2-D torus of 4x4. Every 2-D torus presents one layer in the 3-D torus. The 4x4 rings of a 2-D torus can be interpreted also as a 4-D hypercube. As known from the interconnection networks of parallel computers the hypercube is a very efficient topology for communication networks.

VII. Conclusion and Future Work

The today's car information technology is not able to meet the application requirements in future. An important technological progress for the fulfillment of these requirements is necessary. This may come partly from the already known and established methods of the parallel computing technology.

The basic conditions already exist. First of all the introduction of AUTOSAR, the new common standard in car software engineering, prepares the way for the application of information technology in future by the creation of suitable software modules for newer vehicles.

Secondly the parallel computing technology owns various tools to unify the intra-car communication network and to decrease the number of electronic control units in the car in the future. A real time computer network for the intra-car communication could be a solution to interlink all ECUs of the car. Further a multi-computer system can be built to centralize the car application software. This could reduce the number of ECUs plus the number of cable wiring and plug connections while the scalability and the complexity of car application software has been enhanced.

Thirdly components and methods of standard computer technologies can be used. The portability of application software provides the ability to adopt newer computer technologies in future. The wide spread of car electronics and standard computer technologies allows the use of proportional inexpensive hardware components. As seen in history very new innovations, e.g. the anti-lock braking system (ABS) or the electronic stabilization program (ESP) will be sold firstly with cars of the upper classes. But just a few years later all classes will successively benefit from these innovations.

But nevertheless problems have to be solved which are very special to the automotives. The X-by-wire systems are still a big challenge for the automotive industry. This technology has to operate absolutely safe while being affordable in addition. The energy management and the operational availability will be a matter as well as the quality and cost management.

For research work the Clausthal University of Technology has started the project “ConPar”. ConPar shall be a parallel computer to solve the automotive application software problems of today and in future. For the automotive application software ConPar means:

- very high processing power
- adequate size of memory
- high scalability and flexibility
- replaceable hardware
- reusable application software
- simplified system integration
- quality intensification
- cost reduction

ConPar, in association with CarRing II, will be realized in a mobile test platform, the TUCar. The intention of the TUCar is to bring the full X-by-wire functionality into a vehicle. Doing this way ConPar as well as CarRing II are able demonstrate their full capabilities in a real car.

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