Compared Architectures of Vehicle Control System (Vetronics)

and application to UXV

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ABSTRACT

Many architecture of electronic system, vetronics, does exist already in the civilian area (automotive and more) and in the military field (MBT, IFV, fighters, subs, frigates…). These architectures do control either the dynamics of the vehicle, or the situation awareness and C4I communication.

They integrate an onboard human presence able to play a significant part in the system management and to fix any incoming failure.

What is relatively new for UXV (UXV stands for UAV, UGV and UUV) architecture is evident: the non-presence of human, letting the system operating by itself in every functional mode and with only a weak link to human control. This article is mainly UGV oriented but common features with others robots may be found here.

All things considered, the basic architecture of an UXV must be designed with the actual basics (multiplexed, redundant…), COTS/MOTS components, and specific functional modes due to this particularity. This a must due to cost, time-to-market, buts with a common problem in military field, obsolescence.

An interesting question is the nature of UXV: does it have to be a specifically designed robot, without any possibility to be human driven or is it a manned vehicle with a robotized option as needed?

This presentation will take several models to explain what could be architecture for UXV and how recent development in automotive industry can be used in UXV or for generic AFV, with adaptation.

This paper presents a short historical development of automotive, then a compared architecture with a common view, with vetronics for UXV, and a conclusion with future trends.

A SHORT HISTORY of AUTOMOTIVE and VETRONICS

The 20-70's age.

In the olden times of automotive, architecture was quite simple: linking a button to an actuator, linking mechanically a wheel-drive to the wheels, a throttle pedal to the engine through a cable, a braking pedal to the brake drums and discs by hydraulics pipes. A one to one model.

The 80-00's age.

New criteria appeared: the growing need of new functions leaded by marketing efforts, profitability and security pushed to a new design with a better level of safety. And the complexity of electric harness was not yet sustainable if 2000 cars must be manufactured a day, as quality problems where beginning to be unresolved.
Considering this new aspect, options offered as ABS, air conditioning, electric powered windows are at an upper level of complexity due either to the wiring, the first problem, or the need of a global system approach.
Design and integration of CAN and VAN buses was perceived as the best solution but many bad designs lead to problems, specifically in H1 class.
In parallel, military systems as fighters, subs, frigates and eventually tanks, were starting to use own standards, which were after standardizing problems, working but at a high cost. MIL-1553B is an example. Just note that debugging tools where very poor, not designed for system level. A difficult approach due to the non-deterministic control of CAN, still a problem.

The 00-X0 age.

Automotive manufacturers understand now, that a global approach is a must: many standards as control buses appeared as Flexray, Most, Lin. The physical link is copper or fibber optic based, the cost of a connection point is under 1 €.
Global system approach link the engine, brakes, airbags, steering wheel, suspension to provide a high level of security and certainly a must for quality, reliability. What is the cost paid by a manufacturer obliged to call back one million of vehicles and the bad perception given to the customer (2005).
In parallel, this kind of problem must not happen in a military system, especially in a weapon equipped system. Just imagine a nuke bomber having a serious problem in the navigation and attack system during a mission…

Another new trend in automotive is energy management. As new functions appear, de-icing the rear-window, modulated AC with partial zones, navigation equipments, electric assistance to the steering wheel or even xenon lights, led to a conclusion: the car in traffic messing condition or cold weather, is not able to provide the convenient level of energy. Many ways to resolve this issue.

- Dual batteries, one for common use, the other for engine starting
- 42 V instead of 12 V combined with alterno-starter (a combination of alternator and starter)
- Hybrid engine as used on Prius or DPE[1], with energy braking recuperation. Note that this last concept is already in use on Leclerc MBT turret.

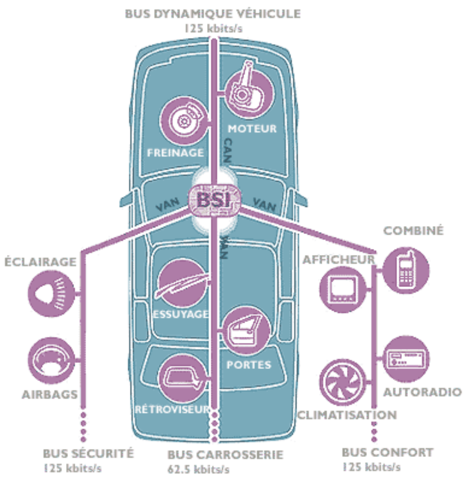
[1] DPE: Démonstrateur à Propulsion Electrique : a contract conducted by GIAT industries to develop an hybrid 6x6 fighting vehicle.

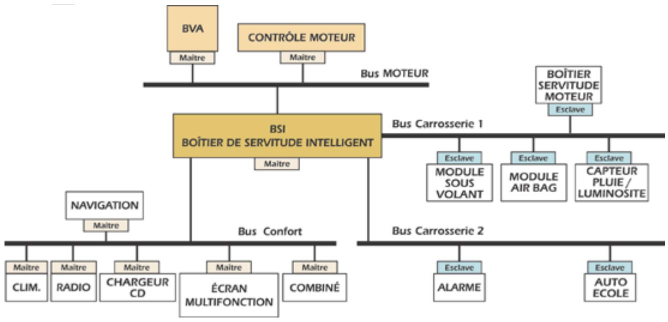
It has to be pointed up that these approaches may be combined. Military vehicle should use such energy management in the next vehicle generation but reliability is at the corner. Global architecture and subsystems as batteries have to be evaluated with respect to the critical issue of a military mission under a GAM-T1 specification (temperature, shocks, acceleration) and now, environment. Automotive industry has the same problem, but only multiplied by a million time…

In conclusion, a parallel approach between what is now available on the civilian market and what is needed for UXV and military vehicles of any nature is relevant with an adaptation of specification: COTS/MOTS can be used with caution.

COMMON ARCHITECTURE DESIGN

The following draft the design architecture of a 90's car.





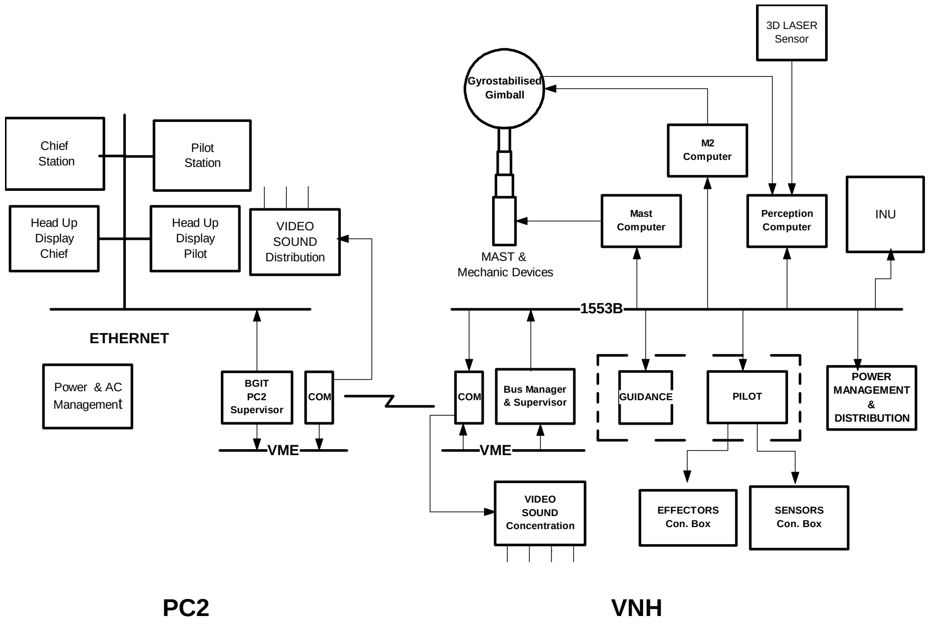
Four buses dynamics, security, MMI and body. The last one is only half speed of the others due to the functional needs.

The BSI is the common computer acting as central intelligence and the gateway controller. A same architecture can be applied to UXV, with a suppression of the MMI function and the airbags feature, if the vehicle will no be used by humans.

Others functions must be analyzed deeper as rear-view mirrors control or door security, depending on the UXV is a pure robot or a robotized vehicle.

Of course, this analysis is not applicable to UAV or UUV.

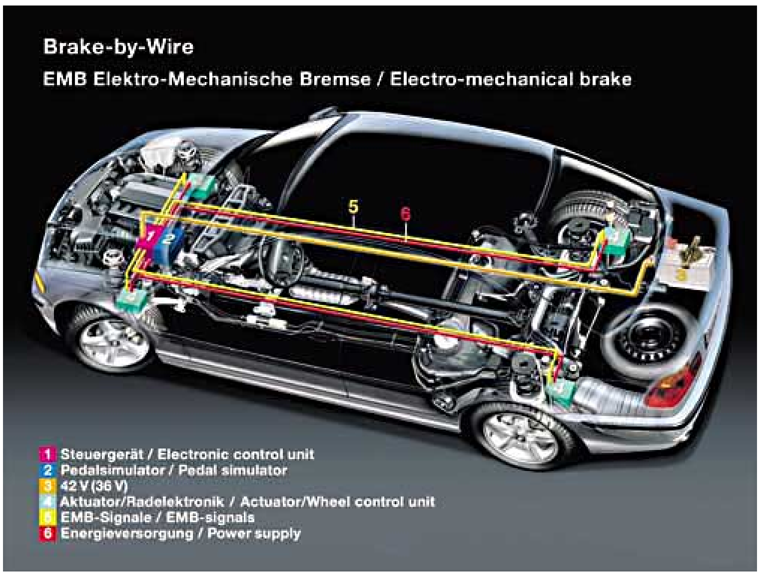
New cars are more and more designed for shared control between the driver and the car. The following picture emphasize on brake-by-wire technology. From now, a degradation mode in braking system oblige the manufacturers, by legislation, to link directly the pedal to the brake. It is the same issue for the driving wheel.



This is the architecture of the Syrano (right of the design) robot based on 1553B bus. Not car architecture but looking like for guidance and pilot functions very close from ESP. Difference is seen on the left side of the picture: human control through radio link, not a human in the vehicle (here it is an armored vehicle on a Wiesel 2 tracked chassis, a 4 tons class).

Controlling a vehicle at any distance (10 km at max for Syrano) is an issue. Not the topic of this article, but a the big issue: teleoperation, semi-autonomy, autonomy, many words about a real problem: how to deal with a 60km/h vehicle running in all terrain navigation without being a little bit concerned about.

Let us see about automotive control, as an inside driver.



Things are changing on automotive: many new cars have an electric handbrake (BMW, Renault…) and electric brakes, what can be seen as the ultimate development, is pushing.
The other trend is wheel drive assistance. We started with nothing in olden time, a tractor view. We have now hydraulic and electric assistance, with a force modulated

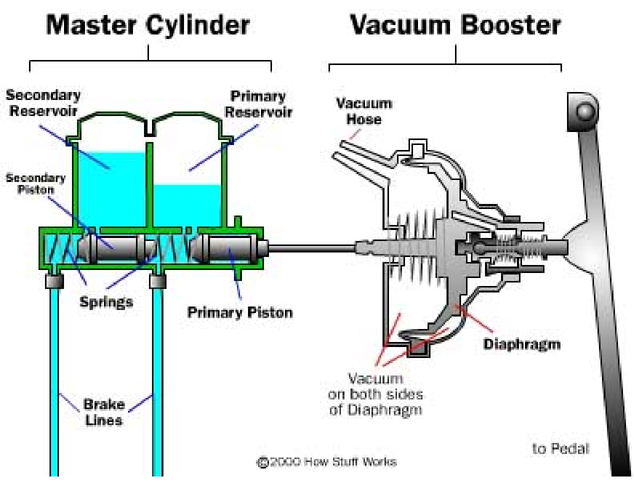
with respect to speed, dynamic attitude and either condition as parking. As said above, the engine control is already done by wire. This control needs a sensor to measure the position and the speed of the action on the driving wheel as well as 2D inertial attitude of the vehicle for ESP function, 3D for SUV.
The combination of these controls enables the control of vehicle dynamics through the well-known ABS, ESP and other ASB derivative functions. An ABS system need the tuning of other 500 parameters, how many for an ESP system?

All these sub-systems can be used in a UXV, more specifically for an UGV. As the sub-system can be controlled through a bus it can easily be used on an UGV.

APPLICATION to UGV
Either bus architecture, or use of already existing sub-systems is applicable to UGV. The idea is to see how a generic modern vehicle can be robotized at a lower cost with a double function, be human driven or be robot driven. Examples given for mobility control.

BUS
CAN bus is now used in military vehicle (VBCI of GIAT industries and Renault Truck Defense) or in the FRES program (UK) of the MilCan, an adapted version of the civilian standard.
The main adaptation is to change the non-deterministic control of CAN to a deterministic one due to “hard” real-time behavior. This evolution has two interests: guarantee of a fast responding system in a determined slot of time, and make easier the integration of the system as a deterministic system: what you order is what is done in a timed schedule.

BRAKES
Security even for an UGV is mandatory, so braking control is.



The left part of the drawing presents the primary and secondary brake lines for security purpose. On the right, the assistance to the driver on the brake pedal is done with the vacuum booster. If adapting a pneumatic valve on a side of the diaphragm, one can control easily the braking force without any mechanical actuator and allowing a human braking of the vehicle simply by disabling the valve, left it closed.

ABS is to be added to the control of the robot, including emergency braking: these functions are fully compatible with an UGV. One can use the odometers on each wheel, without any extra cost.

DIRECTION

Hydraulics with pump, pipes and a non-linear comportment is going to be more and more replaced by electric assistance for the driving wheel.

Electric assistance is under the control of a computer linked to sensors: position and velocity. This is used to lower the force needed on the driving wheel but also to be combined with trajectory control (ESP function) as well as parking aid.

The idea, for UGV, is to revert the electric assistance using the motor but inverting the mechanical gearbox as there is no force on the driving wheel as no driver. The amplifier may be used without any change, just be controlled by another computer, the robot one. A simple by-pass switch insures the commutation between human and robot drive.

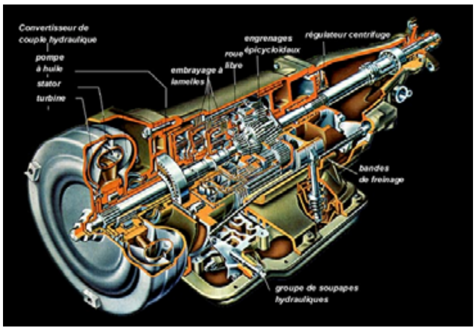
But to add more agility to a wheel-based robot, it is better to disable the ESP function. Many reasons and a legal one: ESP must not control the direction while in action.
Nevertheless, a direct control of the direction while braking, with an ABS at less of 3rd generation, and by controlling same side brakes of the vehicle offers a better dynamic control.
For a robot there is no limitation for comfort in lateral G's as far as the dynamic stability is insured. What is done with 2 axes inertial unit, what can be found with Fog's or integrated silicium device. For robotic purpose, an independent INU seems to be more convenient.

GAS PEDAL

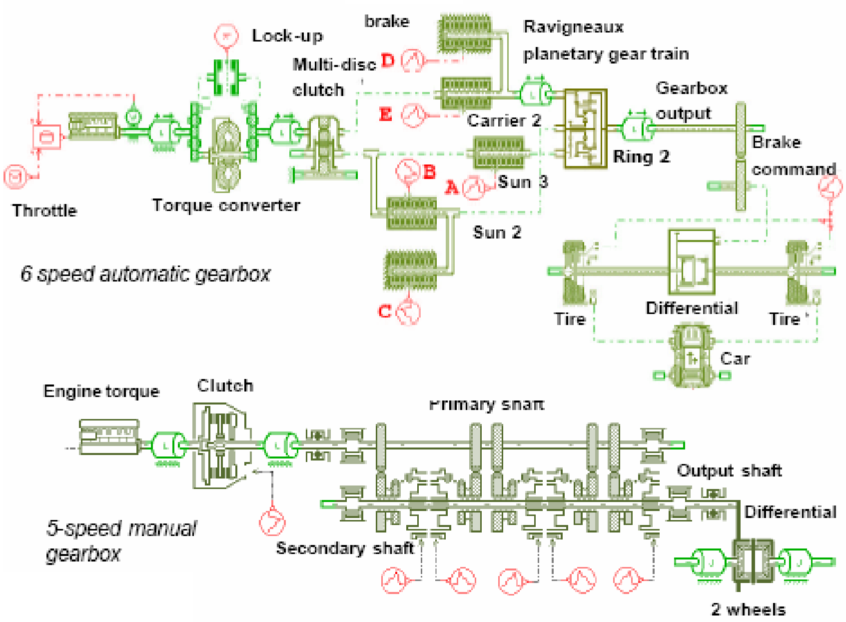
Nothing more to say that new cars, and all diesel engines have a drive-by-wire to control the throttle. And the pedal has a position sensor. The control of such a device is evident.

GEAR BOX

Typical "analogical" gearbox is presented here. Based on hydraulics, pump, valves, sensors and very particular devices.



Evolution is on the way.



Automatic and Manual gearbox

Manual automatic and now robotized gearboxes are on actual and coming vehicles. The best for UGVs, and for drivers, is of course the robotized gearbox as the last Quickshift from Renault.

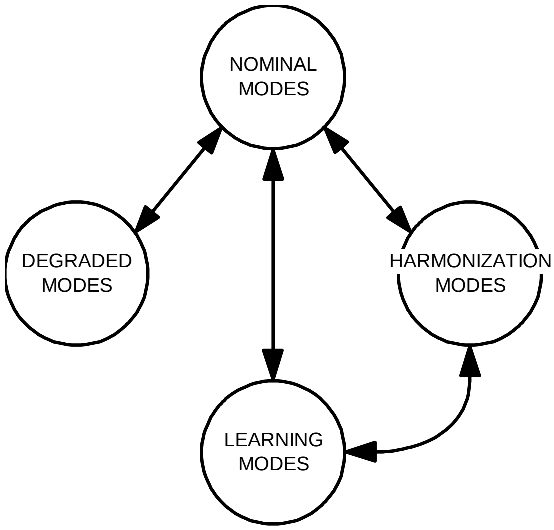
As far it may be controlled trough paddles, any embedded computer may control it.

The main issue is to get specific sensors outputs as engine speed, the gear engaged etc…

From now, we have a complete car able to be transformed to an UXV. But what is needed to transform a car to UXV to be fully under control? Intelligence. A great word as far we now.

Control and Command

As seen before, all components are present in the automotive world.
UXV, and specifically UGV need more: a shared control between operator and the robot. A mandatory design for robots is a mode oriented one. The robot has to be in already designed modes, no more, no less. A steady state in any condition.



Modes transition (simplified)

Modes are designed to control the robot in any situation: nominal mode is the normal. Degraded mode is operating as any incoming failure occurs. In this latest state, robot control must deal with diverse situation without any help, as in automotive world where a car is supported by human assistance. The most complex mode.
Steady state means a known level of control in any situations and is the graal for robotics control. Situation uncertainty is the common view and to control it, a robust architecture must be implemented.

Robot control has to be understood as a balanced system: a fully controlled system, under human supervision or an autonomous one, able to care with any happening hazard such as fixed obstacle, and more as moving obstacle, or deceptive obstacle as ponds, moving trees… And this is the only matter addressed for mobility, mission is another issue.
Robotics research is a passion and the most that can be done at now, is to propose what can be named a «shy» system.

The present UGV science is not still able to do everything, but must be able to protect the robot itself and to support for what it is built, the mission as the only and final requirement.