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Open architecture vehicles of the future

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OVERVIEW

The last four decades have seen an explosion of open architecture electronics, computers, social media, modular operating systems, sensors, communication links, etc., all based on standardized highly certified and cost effective modules provided by a responsive supply chain. Virtually no progress of a similar nature for electro-mechanical systems (orthotics, aircraft, vehicles, surgery, manufacturing cells, etc.) has occurred [1]. A companion paper [2] on the Next Wave of Technology shows that the previous electronics wave was necessary to prepare the foundation to this emerging technology to continuously enhance performance-to-cost ratios for a very wide range of applications that form the core of the discipline of mechanical engineering. Major government agencies (especially in Europe and the U.S.) have begun to structure their programs on "popular" ideas reinforced by the news media. Solid science for a multitude of electro-mechanical applications (see the NWT paper) is being displaced in favor of cloud computing, big data, neuro-science, nano-science, etc. The result is now becoming severe. The weakness of any one technology (in this case, the mechanicals) forms a weak link to make the resulting systems of technologies weak. The large failed investment of $30 billion for the Future Combat System (FCS) by the Army is proof of this continuing and growing imbalance. In this paper, we illustrate this large view development objective by concentrating on open architecture vehicles. As may be understood, only a portion of the required development can be described in this short paper.

List of topics for open architecture vehicles

1. *More-electric Vehicles*: The range of vehicles that could be considered is anything that moves on paved or rough terrain surfaces including cars, buses, military vehicles, robot platforms, etc. All of these will use intelligent corners (4 DOF) to dramatically expand choices to meet ever-expanding performance goals, all under human command and response in milli-sec.
2. *All-electric/Modular Automobile*: The emphasis in modern automobiles is primarily to make the I.C. engine more efficient and power dense and to create hybrid power management and energy storage which continues to make the automobile more expensive with the real benefit of durability. The issue of aftermarket maintenance and refreshment has not been dealt with. Open architecture for all certified components from multiple suppliers, as has been achieved for computers, will address this costly problem, give more choice to the consumer, and permit rapid reconfiguration by the OEM. This openness will only occur if the mechanicals do as the electricals have done — achieve plug-and-play throughout the automobile [3].
3. *Hybrid Electric Bus*: The bus is a standard/large fleet vehicle which because of its start/stop duty cycle benefits from stored energy retrieved during speed reduction. Whether the energy is stored in a flywheel, hydraulically, or in batteries is not yet economically settled. Clearly, the winner will be the process with the fewest energy loss transformations of which the battery appears to be the least attractive. Unfortunately, cost is an issue in that the hybrid bus premium is 40% of the cost of a normal bus. Further, there are significant downstream costs to assure continued fuel reduction of 40 to 50%.

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4. *Open Architecture Mechanical Systems*: To open up the architecture of any generalized system first requires standards for the interfaces among all the components to permit plug-and-play. Progress in assembly of mechanical systems awaited the standardization of screw threads in 1880. Now, we need the same for quick-change interfaces for a wide range of components with emphasis on cost, scaling, precision, geometry (linear, circular), stiffness, etc.
   Once the interface issue is treated, then it becomes necessary to create the equivalent of a minimum set of highly certified intelligent actuators (the drivers of electro-mechanical systems, as the chip is for electronic systems). This minimum set must fit the broadest population of systems (in this case, vehicles). The measure of performance/cost ratio would, then, determine who the ultimate suppliers are. Fortunately, the self-contained actuator (motor, gear train, sensors, controllers, interfaces, etc.) is at the correct level of granularity to achieve this essential revolution.
5. *Conceptual More-Electric JLTV*: A critical example of an open architecture vehicle would be a more-electric Joint Light Tactical Vehicle (JLTV). The late failure of the FCS illustrates the urgency to make a modular, rapidly reconfigurable and refreshed, easily repaired in the field by means of a minimum set of spares vehicle of ever-improving performance to cost. The vehicle armor would be the frame and all components would be protected under the armor except perhaps the in-wheel drives. Each wheel would be part of a standardized 4 DOF intelligent corner (suspension, camber, steering, and wheel drive) which, then, becomes the heart of the maneuverability of the vehicle, enabling plug-and-play of these corners to achieve the one thing the military has yet to accomplish — to always be able to reconfigure the platform to meet the immediate or unknown future threat.
6. *Future Vehicle Component Development*: We list here ten essential component technologies that are necessary to enhance performance, respond to human command and reduce cost of open architecture vehicles. This listing enables even small development teams to make contributions to the larger development objective in software, sensors, wheel drives, road/surface awareness, decision making, criteria development, etc. We also need the equivalent of Intel, Microsoft, and DELL to do in-depth components, the operating system, and the supply chain assembly to structure the large network of required suppliers. For example, the last decade has shown that essential sensors will cost between $1 and $5 to generate data on the physical condition of all components and the system, itself, to enable real-time decision making (in milli-sec.) to respond to human command.
7. *Planetary Rovers*: The vehicle community does not have a thriving open literature, but the space-based planetary rover people do, as represented by excellent work on-going worldwide (China, Japan, Europe, U.S.). Much of this work deals with long-range rover mission planning but because of the need to deliver an operating system, all component, system, and terrain technologies must be addressed. This includes on-board power communications, vehicle architecture and dexterity, actuator drives, sensors, wheel/surface interface, etc. The result is some very innovative vehicles out of NASA, China, and Japan. Also there is a move towards special wheels, in-wheel drives, multiple steered wheels, obstacle management, etc. Autonomy, not real-time human command, dominates this work. In-depth testing over years must occur before deployment. A critical need is to reduce weight which affects the power supply and the actuator components. Power density is not the issue; dexterity and maneuverability are. This includes task performance of on-board manipulators and specialized instrument packages.
8. *Intelligent Tire*: The terra-mechanics community has experimentally studied the tire/surface interface for 5(+) decades, especially for rough terrain operation and for weather-related operation on prepared surfaces. This has resulted in hundreds of published charts on slip, skidding, coefficient of friction, effects of tire pressure, rolling resistance, deflection, etc., etc. But, virtually none of this has been implemented in real time. To do so will require tire-embedded sensors, suspension-related sensors, and actuator sensors to fully generate operational data in real time (in this case, in less than a milli-sec.) and these sensors must be of very low cost — say, for a 4 up to 14-wheeled vehicle. Until this is achieved, perhaps 50% of the required operational data for the vehicle will be unavailable to real-time data-based decisions which, then, lead to guesswork based on empirical data from general operational experience. This simply is not good enough. We must encourage the development of intelligent tires for improved efficiency, traction, and safety over a wide range of surface and weather conditions.
9. *Tire Performance Maps*: The ultimate goal is to embed a wide range of empirical data for tires in maps that can be retrieved instantaneously (milli-sec.) to accurately represent a tire's real performance so that the whole vehicle would be operationally “intelligent” and capable of internal criteria-based decisions under human command and human-set priorities (just as we now do for pilots of military aircraft). Unfortunately, this, then, requires a lot of up-front expenditure to measure and parametrically record these maps for a wide range of surfaces (say, ten classes) and diverse weather conditions (also, a minimum of ten distinct affects). And, we have to do this for each unique tire and then must predict the changes in these maps as the tire degrades during use. Clearly, this necessary capability will require considerable science development based on design of experiments to best define these maps with a minimum of test data to a useful level of accuracy (uncertainty).
10. *The TWIRE*: The tire population covers a very broad range of products for automobiles, construction machinery, agriculture, military, racing, etc. Special examples exist for planetary rovers, amphibious vehicles, heavy mining trucks, etc. The TWEEL, a tire without compressed air, has been given considerable attention by Siemens. Here, we wish to describe the TWIRE, which combines features of a track, wheel, and tire. It is intended for use in severe off-road conditions, especially to permit mission reconfigurability for the military. TWIREs capable of 3, 4, and 5 tons are envisioned, depending on the size and mission complexity of the vehicle. At 5 tons, it is necessary to go from a load patch of 100 in.^{2} for on-road operation up to 500 to 600 in.^{2} for off-road. The tread is made up of a finite number of rigid “blocks” tied together with high quality flexible hinges. The inside of the TWIRE has 3 distinct volumes which can be separately pressurized to shape the carcass to best match the needs of the surface interface. These 3 volumes are separated by panels which have sufficient structural integrity to maintain the TWIRE's shape, even when traversing a slope. Clearly, a lot of materials development will be required to reduce energy losses and minimize temperature affects and fatigue failure. Nonetheless, to make wheeled military vehicles competitive with tracked vehicles at 5 tons per wheel, this development is essential [4].