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A Review on Vehicular Cyber Physical Systems

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Abstract— *Automobiles, since its early development, has been designed and developed as a machine and has worked in accordance to it. But this idealization has come with limitations such as Traffic and parking management, Safety assurance, road accidents prevention, pollution regulation. Cyber Physical Systems is an upcoming field which integrates computation, networking and physical processes. Now a day, to make any device smart, Cyber Physical System is considered as an option to be incorporated in the device system. But Cyber Physical System as a field is still in its infancy. Therefore, in this paper the implications of Cyber Physical Systems in automobiles are studied not only in the above mentioned limitations of automobiles as a machine but also in the development of electric cars and driver less vehicles. Researchers have suggested use of technology such as Global Positioning System, Dedicated Short Range Communication protocol, Vehicular ad hoc Network, Adaptive Cruise Control, Intelligent Transport System and cloud assistance to tackle the traffic and parking management and road safety problems. Optimization of the electric motor, Heating Ventilation and Air Conditioning system as well as electronic circuit power requests in an electric vehicle are explored via the various techniques and algorithms suggested by researchers. Use of Wireless systems combined with cyber physical system is studied for the development of driverless vehicle. Application of Cyber Physical Systems was also found in fast multicore co-simulation of internal combustion engine. But we found the absence of human in loop control as a major factor in the Vehicular Cyber Physical System research. Hence we identified the limitations related to the above problem statement and the need for incorporation of human behavioral pattern in Vehicular Cyber Physical Systems.*

Key Words: Cyber Physical System, Global Positioning System, Dedicated Short Range Communication, Vehicular ad hoc Network, Adaptive Cruise Control, Intelligent Transport System, Heating Ventilation and Air Conditioning.

I. INTRODUCTION

Since the earliest known invention of wheel in 3500 A.D. in Mesopotamia, various means of transportation have been developed. So that's how early primitive vehicles came to be driven on wheels but the drive was given through animals for e.g. in bullock cart. Therefore over the years, the need for self-propelled vehicle was identified. Since then various engines have been developed from the steam engines of yesteryear to petrol and diesel engines of today. The first steam engines were developed in 1600s and slowly phased out in later stages of automobile development due to low thermal efficiency, space constraints and the advent of internal combustion engine. As automobiles were improvised, new systems for braking, transmission and suspension were developed. Years of research and experience lead to the automobile we know today in the 21st century. Now the design of a vehicle has not only been limited to location to location transportation but for comfort, leisure, racing, thrill seeking etc. In the last century, vehicle as a requirement transformed from a need to a desire for a human being. This leads to the development of billion dollar automobile manufacturing industries. This led to a boom in automobile sales. But today this has led to new problems such as increased traffic congestions, parking inefficiency and insufficiency, road accidents, traffic rules violations, noise and air pollution. All these problems have one characteristic in common which is the involvement of humans in automobile control. If given a thought, it can be found that all these problems are because of human chaotic nature. Careless driving, total disregard for human life and property, ignorance to world problems such as fuel depletion, global warming – these all can be found in today's humans. It was found that to eliminate all the above problems, human factor has to be eliminated from automobile control.

Till now an automobile was seen as a complete system but led to the limitations as mentioned above. Now it has become imperative to think of automobile as a part of a bigger system which consists of other on-road vehicles with real time communication. And in addition to that, make it completely aware of its surroundings. So in a nutshell, give way to development of autonomous vehicles. Pollution and fuel exhaustion related problems can be solved by the development of electric vehicles. But this must require a system not only to accommodate above solution but also to manage them. In this paper, Cyber physical systems were explored to solve the above problems.

Cyber Physical Systems is the synergistic integration of networking, computation and physical processes. Their application in vehicular technology have been long researched and studied since the idea of autonomous vehicles came into picture.

Problems pertaining to road are solved by technologies like V.A.N.E.T, A.C.C., Real time machine to machine communication, D.S.R.C protocol to implement various ideas. Vehicle platooning is done to manage traffic efficiently in which directional grouping is done of vehicles with dynamic vehicular group sorting at each pathway segment. Road safety is a big crisis today and it is tackled by use of D.S.R.C protocol and road and on board equipment. Constant vehicle to vehicle and vehicle to static R.S.E helps to do dynamic traffic data mining which in turn helps to avoid any traffic accidents due to unpredictable incidents. By G.P.S, area mapping and past vehicle location based data, various algorithms are devised for efficient and non-chaotic parking system.

Today, viewing the escalation of climatic problems due to pollution and global warming, electric vehicles are being considered as an option in place of I.C engine vehicles because of their environment friendly operation on electricity as against fuel combustion in I.C engine. But the dependency of E.V. on Battery as an energy source raises various problems such as degradation of quality of control, battery life and capacity. In addition, complete electronic system, H.V.A.C system and electric motor draws power from battery which in turn degrades it over time of usage. One potential solution is to design controller and control algorithms to minimize energy consumption. Taking electric motor power consumption along with H.V.A.C power requests as decision variables in control algorithm for H.V.A.C has become imperative to sustain and prolong battery life.

Today optimizing any vehicular design in consideration with dynamic variables during its operation has become a challenge. I.C engine is one such component which has to be optimized to reduce fuel consumption, maximize power generation and decrease harmfulness of exhaust gases. But dynamic mining of data during I.C engine operation for its analysis becomes a challenge due to its high frequency of operation. Therefore the hybrid complex dynamic system is divided in to subsystems by separating the air path from the cylinders and then isolating the cylinders from each other. This kind splitting allows the reduction of number of events acting on each subsystem. Then each individual events are combined with ordinary differential and differential algebraic equations which in directly prevents the usual sequential single threaded simulation tools to reach fast simulation speeds. This co-simulation technique leads to significant improvements in accuracy of the existent modular co-simulation, computation time and to provide a supra-linear speed up.

II. LITERATURE REVIEW

Samarjit Chakraborty, Mohammad Abdullah, Al Faruque, Wanli Chang, Dip Goswami, Marilyn Wolf, Qi Zhu, With the advent of electric vehicles and software control comes various design constraints such as battery life, security, system stability, safety, vehicle cost and passenger comfort. Optimization of all the above mentioned variables results into prolonged life and optimum quality of the vehicle. H.V.A.C. is made C.P.S oriented by not only taking into account cabin temperature and state of H.V.A.C. device but also electric motor's power request. These variables are optimized to give utmost passenger comfort and prolonged battery life. Optimizing control algorithms and variables for Feedback control systems, Resource-aware automotive control software design, Computation-aware control systems design, Memory-aware control systems design, Battery-aware and reliability-aware controllers gives maximum stability, Quality of control, battery usage and life. Co-designing of cyber security across embedded system without compromising control performance is necessary. It is concluded that integrating the design of control algorithms, embedded hardware and software design leads to lower costs and better system quality and reliability. Hence innovation in embedded technology and new techniques in control theory are required.

Dongyao Jia, Kejie Lu, Jianping Wang, Xiang Zhang, Xuemin Shen, In future, it is foreseen that there will be a substantial increase in number of vehicles which will give rise to increased traffic congestions, air and noise pollution, fuel consumption etc. These problems can be tackled by forming the traffic dynamics into platoon based i.e. directional grouping of the vehicles to make traffic management efficient and safe. Since platoon is complex system, modeling of the platoon system and control strategies is done using Vehicular Networking Standards and Architecture, Traffic Mobility Models, Adaptive cruise control (ACC) system, intelligent transportation system (ITS),vehicular ad hoc network (VANET) and many more. The downfalls of Platoon based Vehicular C.P.S are studied. It is concluded that Platoon Based Traffic Management using Cyber Physical Systems is the future of modern transport system and has potential to make today's traffic system safe, time saving and energy efficient.

Abir Ben Khaled, Mongi Ben Gaid, Nicolas Pernet, Daniel Simon, This paper deals with the problems related to the efficient parallel co-simulation of hybrid dynamical systems. A finely-grained co-simulation method using

numerical integration has been introduced. Also introduction of specifications FMI and HIL has solved the problems faced such as diversity in modelling. But the existing system-level simulation software is unable to exploit multi-core processors. Parallelization is studied across the method using Runge-Kutta method, Partial differentiation method respectively. Parallelization across model is studied using waveform relaxation, transmission modelling and modular time integration. This study mainly focuses on numerical solvers based on time discretization. It is expected in future to compare their efficiency to those based on state quantization since they are suitable for discontinuous ODEs. Finally, a spark ignition Renault F4RT engine was modelled.

Daiheng Ni, Hong Liu, Wei Ding, Yuanchang Xie, Honggang Wang, Hossein Pishro-Nik, Qian Yu,Since human drivers are relied upon to analyze their surroundings, decide actions, execute control maneuvers and take route choices, it gives rise to road accidents and congestions which are the result of human errors-deliberate or undeliberate. These problems are addressed by connected vehicle technology and integration of cyber and physical systems. Real-time and reliable vehicle communication are enabled using D.S.R.C protocol and V.A.N.E.T. to reduce probability of collisions. Mining of Traffic data is done using R.S.E. and O.B.E. units to deduce current and anticipate future traffic conditions at locations, with or without R.S.E coverage, and use this traffic information for dynamic vehicle routing. Vehicular coordination is achieved by traffic flow optimization. It is concluded that vehicle automation and road safety can be revolutionized by merging knowledge of various fields into science of Cyber Physical Systems in transportation and put it into application.

Jiafu Wan, Hui Suo, Hehua Yan, Jianqi Liu, requirements to develop a test platform is analyzed by taking unmanned vehicle with Wireless Sensor Networks (WSNs) navigation as an example. The use and scope of WSNs and CPS in other fields like military target tracking and surveillance, natural disaster relief, biomedical health monitoring, hazardous environment exploration and seismic sensing are explored.
An economical test platform is chosen to conduct theoretical and practical experiments and Linux was chosen as the operating system. A real-time scenario is created and the vehicle is made to decide and travel to the finish point taking the best possible route by installing the sensors and control algorithms on both side of the highway. An accuracy of 0.67m was achieved in the tests. Different test scenarios were studied and aspects like system resource allocation, energy control, secure control, transmission and management, model-based software design, system modeling, control technology were tested and verified. The challenges faced by integrating the virtual cyber world with the real physical world using CPS are analyzed. Major challenges that might surface in the future are abstractions, model-based development, control and hybrid systems, sensor and mobile networks, robustness, reliability, safety and security, verification and certification. Finally an insight is provided to promote further advancements in WSNs using the CPS.

Daniel Work, Alexandre Bayen, and Quinn Jacobson,In this study, the present state of vehicular CPS is overviewed. Fundamental limitations such as limited information, inadequacy to address human-centric needs, pace of adaptation are studied. Vehicular CPS is compared with the open source structure with a less centralized control in mobile phone industry. Collaboration of the idea of embedded humans with that of cyber physical system and their interactions is done. The problems faced by dedicated short range communication (DSRC) and the intrusion of geo-referenced data with respect to privacy are studied. Finally, an experiment successfully demonstrated the use of a new technology for highway monitoring with GPS equipped mobile phones

Jiafu Wan, Min Chen, Feng Xia, Di Li, and Keliang Zhou, areas of application of Machine-to-Machine (M2M) were discussed and interfacing of M2M and CPS to eliminate human involvement was predicted. Concept of IoT was used in the CPS to help it focus on intelligentizing interaction, interactive applications, cross-layer optimization, cross-domain optimization, distributed real-time control, etc. M2M architecture was divided into 3 main areas, namely M2M area domain, Network domain and Application domain. Various applications of M2M such as Historic Preservation, Manufacturing Systems and Home Networks were elaborated. Some of the challenges faced while developing M2M systems were listed, for e.g. cost, inter-connecting two M2Ms, etc. An algorithm for the path finding was developed and tested. An example was implemented based on a left turn taking car at an intersection. When a certain vehicle is considered hazardous, other vehicles are stopped in their tracks to avoid any mishap. Selection of braking degree i.e. how to stop or slow down or how much to slow down, was obtained by calculations. Some other problems include emergency vehicle routing, dealing with extreme-events and failures (failure-safe to failure operational), security and privacy, etc. The comparison between CPS and M2M was done on the basis of Communication Pattern, Network Formation, Power Management, Network Connectivity and Coverage, Knowledge Mining, Quality of Services, Real-time Feedback Control and Standards. Finally for CPS to make progress and stimulate more technological development in the future, M2M will be used.

Christian Berger, Bernhard Rumpe, The international competition DARPA Urban Challenge took place in November 2007. The challenge of the competition was to develop an autonomous automobile which will be able to travel on the modern city roads. Study was done to understand the contributions made in the last few years in order to further reduce traffic jams, to save fuel, and most important to prevent casualties and fatalities. The vehicles were lined with sensors from all sides to detect proximity with other vehicles. An accuracy of 0.1 meter was achieved. A ROM of 10MB/min was installed to collect all the surrounding data at real-time frequency. This was done to achieve localization and perceiving the vehicle's environment. Various methods and processes were used to understand and analyze the surrounding's data. Some of the methods that are used are named as follows, [HW11], [CWW11], [WGR11a], [SUWL10], etc. The software was such developed that it changes according to the real-time surrounding environment. After acquiring data from the surroundings, Long term goals and short term goals were decided to be acted upon. The best possible track for the vehicle was decided. The software was upgraded to include pedestrian and two-wheelers in the surrounding data analysis. Numerous test runs were performed in simulated as well as in 'real-time' conditions. Finally the plus points of all the teams competing in the DARPA challenge were listed. New methods were discovered in CPS and trend in the evolution of autonomously driving vehicles were seen.

Jason Madden, Bruce McMillin, Anik Sinha, Some security threats were observed in the Cyber Physical System(CPS) regarding external and environmental encroachments in a particular system. An example was developed with an automated engine management system (smart cruise control) and observations were made on the data which is being transferred to other systems from the main controller. A method was developed to separate the confidential information and the observable or sharable information. For this, Controlled Area Network (CAN) is used to communicate between the vehicle's Engine Management System (EMS). Two models namely Non-deducibility Model and Non-inference Model are formed to enhance the security and restrict the trace. Five theorems or problem statements were proposed. Each theorem was built up on three scenarios namely Standard Cruise, Perfect Cruise and Random Cruise. The theorems were as follows:

1. Vehicle operation is (non-deducibility) secure when traveling up-hill for standard and random cruise controls.
2. Vehicle operation is (non-deducibility) secure when traveling down-hill for standard and random cruise controls.
3. Vehicle operation is not (non-deducibility) secure when traveling across a flat terrain.
4. Vehicle operation is not (non-inference) secure when traveling down-hill or traveling up hill.
5. Vehicle operation is not (non-inference) secure when traveling across a flat surface and during increase or decrease of speed.

It was concluded that the CPS system will naturally import some confidential data but with the use of natural obfuscation certain high level information can be hidden. Thus it is an essential component for the CPS.

*Jiafu Wan, Daqiang Zhang, Shengjie Zhao, Laurence T. Yang, and Jaime Lloret,*In this study, an idea of cloud-assisted context-aware CPS by integrating various technologies such as mobile cloud computing, context-aware technology, DSRC, vehicular networks with the capabilities of decision making and autonomous control is suggested. As for the scalability of cloud services and computation layers, the architecture of a CVC is classified into three interactive layers: the vehicle computational layer, the location computational layer, and the cloud computational layer. Two remarkable service components such as vehicular social networks and context aware vehicular security were analyzed. A case study is performed based on context aware dynamic parking services using wireless sensors networks and cloud computing, Vehicular clouds consisted of three types VTC, VAC and VWC. The VWC combined the features of both VTC and VAC to serve the roles of the vehicle as infrastructure and end users simultaneously. Finally, some future research directions and possible solutions to improve the performance and QoS of cloud-assisted VCPS were proposed.

III CONCLUSION

After studying all the above papers, we observed that automobile as a system in itself and as a part of vehicular traffic system is optimized by use of Cyber Physical Systems but it is still in the process of implementation. The above stated problems were tackled by eliminating human input to automobile control. But human as a factor seemed to be absent for consideration in design of control algorithms and data mining. Furthermore, it is identified that since vehicle is made to transport humans then it becomes imperative to include humans in feedback control. This means that data acquisition must not only be

from the vehicular physical environment but also from humans as a major source. Human must be a major factor in the decision making as well as operation running process, since vehicle is for the humans and not the other way round. Some of the bodily changes in the human can be measured with electroencephalography (EEG), electrocardiography (ECG), and electromyography (EMG), which measure electrical signals emitted by the brain, heart, and skeletal muscles, respectively. Human facial expression can also become a source of identification of discomfort while transportation in the vehicle. All the data from above data acquisition techniques if properly processed can be used to measure human variables such as comfort, disease, wellbeing, intoxication etc. These changes when integrated with the environmental changes, makes the automobile more aware to take decisions. But the decisions must be characterized in accordance with their complexity. Easy and frequent decisions must be taken by the processing unit and the complex and life altering decisions must be taken by human to avoid any ethical dilemma. Thus with this division of labor, the system can be enhanced for sensing the outer environment.

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