

# ELECTRONIC SOLUTION BASED ON MICRO-CONTROLLER AT91SAM7S256 FOR PLATOONING MULTI-AGENT SYSTEM IMPLEMENTATION

José M. Rodríguez, AbdelBaset M. H. Awawdeh, Felipe Espinosa, Julio Pastor, Fernando Valdés  
*Department of Electronics, University of Alcalá, 28805 Alcalá de Henares-Madrid, Spain.*

Miguel A. Ruiz, Antonio Gil  
*High Tecnology and Homologation Center, University of Alcalá, 28805 Alcalá de Henares-Madrid, Spain.*

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**Abstract:** In this work a low cost electronic solution adapted for control and communication of a convoy of electrical vehicle prototypes based on multi-agent system -MAS- is presented. From the obtained results in previous works, focused on mobile platforms with PC architecture and Bluetooth communication module, a new electronic system has been designed based on the 32 bits microcontroller AT91SAM7S256 and the communication module nRF2401A. With which, it obtains a greater integration of the final mobile prototype and a greater communication capability between the devices connected in wireless network.

## 1 INTRODUCTION

Road transport accidents and contamination as well as traffic congestion have been some of the most important problems to solve in the last years (Ioannou, R, 2002; Zuylen, H. J., et al., 2000). Many of the proposed solutions based on cooperative-driving, especially vehicles platooning (Yamamura, Y., et al., 2002), which is defined as a group of vehicles whose actions in the road are coordinated by means of communication to reduce platoon oscillations and eliminate the so called “slinky effect” or “string-instability” which refers to the amplification of the peak of the error from vehicle to vehicle up stream the last one.

This justifies the dedicated effort to realize studies and projects in the platoon guidance field. Such as: NAVLAB of Carnegie University (Gowdy, J., et al., 1997), PATH related to University of California (PATH, 1998; PATH, 2003), PROMETHEUS handles a part of the “Eureka” European program (Clarke, N., 1995), ARGO of Parma and Pavia Universities (Broggi, A., et al., 1999), PRAXITELE proposed by INRIA (Massot, M.H., et al., 1999; Laugier, C., et al., 1999),

CHAUFFEUR (Chauffeur, 2006), CARTALK 2000 which brings up by the cooperation among automotive electronics companies (Bosch, Siemens, etc.) and Colonia and Stuttgart universities (Reichardt, D., et al., 2002; Maihöfer, C., et al., 2004), MIMICS carried up by university of Murcia and Valencia Polytechnic School (Martínez-Barberá, H., et al., 2003).

In 2002 the European Commission lunched an initiative called CIVITAS (Civitas, 2002) to improve the urban transport by means of innovators methods, strategies, technologies and infrastructures. From these is possible to emphasize:

a) Platoon of vehicles public or private, clean and profitable as far as costs and energy, and the necessary infrastructure.

b) Strategies of demand management based on the access restrictions to the centric zones and other sensible zones.

c) Innovators strategies for management of mobility demand.

d) Integration of the transport management systems and the associated information services.

In the Department of Electronics in University of Alcalá various works, in platoon guidance, have

been realized in different aspects: on-line / off-line trajectory generation and representation as a set-of-points considering linear as well as non-linear trajectory (Awawdeh, A.M.H., et al., 2004-a), multi-agents system applied to vehicles platooning (Awawdeh, A.M.H., et al., 2002; Awawdeh, A.M.H., et al., 2004-b), lateral and longitudinal control to ensure string-stability and to reduce lateral and longitudinal oscillations (Awawdeh, A.M.H., et al., 2004-c; Awawdeh, A.M.H., et al., 2004-d). These works have been developed as a part of COVE project, which deals with platoon implementation (formation and driving) using multi-agent system in transport contexts characterized by great number of potential users where also transportation units circulate with low speeds (less than 40km/h). Such as: airports, historical-cultural centres of millennial cities, thematic parks, business parks, university's campus, etc. In these cases, the traffic ordination based on conventional vehicles is problematic and even prohibitive. Furthermore; because of the curvature variation in trajectory (soft and hard variation), the tracking becomes more important than vehicle's velocity. For that; one or more platoons formed by electrical vehicles have been proposed. In those the first unit (the lead one) drives the platoon to reach the asked station (stop points), which has been solicited by user by means of a cell-phone. As seen in figure 1.



Figure 1: Vehicles platooning attending to the user petition of transport service.

It was shown that for identical vehicles, it is impossible to achieve string stability for spacing distance error using decentralized identical controllers (Maziar, E., et al., 2004; Chaibet, A., et al., 2005). For that, new control strategies and architectures have been designed to communicate Platoon's members together, in order to get information about the intentions of the lead vehicle and the preceding one. Two of the most important architectures that have been implemented in the platoon guidance field are: layers architecture (Varaiya, et al., 1994; Varaiya and Horowitz, 2000) and agents' architecture (Matsui, et al., 2000; Hallé, et al., 2003). In layer architecture, the hierarchical structure controls the vehicles, but in second architecture each vehicle represented by one agent is

able to communicate with the others to achieve the cooperative driving and the vehicle platooning.

The object of the mentioned works and researches is vehicles platooning (guidance and formation) in linear and quasi-linear trajectory (highways), where the lateral velocity is approximately zero compared with the longitudinal one. Nevertheless, the COVE project focuses on transport scenarios where the non-linear trajectory and the route selection are more important than the speed. For that, new architecture has been carried out including three agents for the followers and two for the leader.

The rest of this paper has been structured in form that: the second section presents the multi-agent architecture developed for guidance and formation platooning. The third part details the agent structure and simulation tool designed for its evaluation. Furthermore it details the interaction between agents. The fourth part presents the novel low cost electronic solution proposed to implement the MAS based on the 32 bit microcontroller: AT91SAM7S256. Summing up, part fifth is dedicated to conclusions.

## 2 MULTI-AGENT SYSTEM DESCRIPTION

The platoon prototype under test is formed by full automated followers and a leader remotely controlled. This one deals with the trajectory generation for the rest of platoon members, and the linking-maneuvers organization such as splitting; merging and following.

Figure 2 presents the control hierarchy designed to realize the basic tasks of platoon guidance (Awawdeh A.M.H et al, 2004-b). The leader control logic must solve the trajectory generation based on its actual location and the anticipated curvature, and broadcasts this information to the rest of platoon member, the decision making takes into account the norms and the traffic conditions in addition to the number of units in the platoon and, finally, the possible communication with other leaders of other convoys to guarantee safe displacements and the traffic flow balance.

The followers control logic must give solutions to the exchange of information relative to the state of movement of the leader and other followers (the first two followers and the preceding unit). Furthermore, it has to govern the system of traction and direction

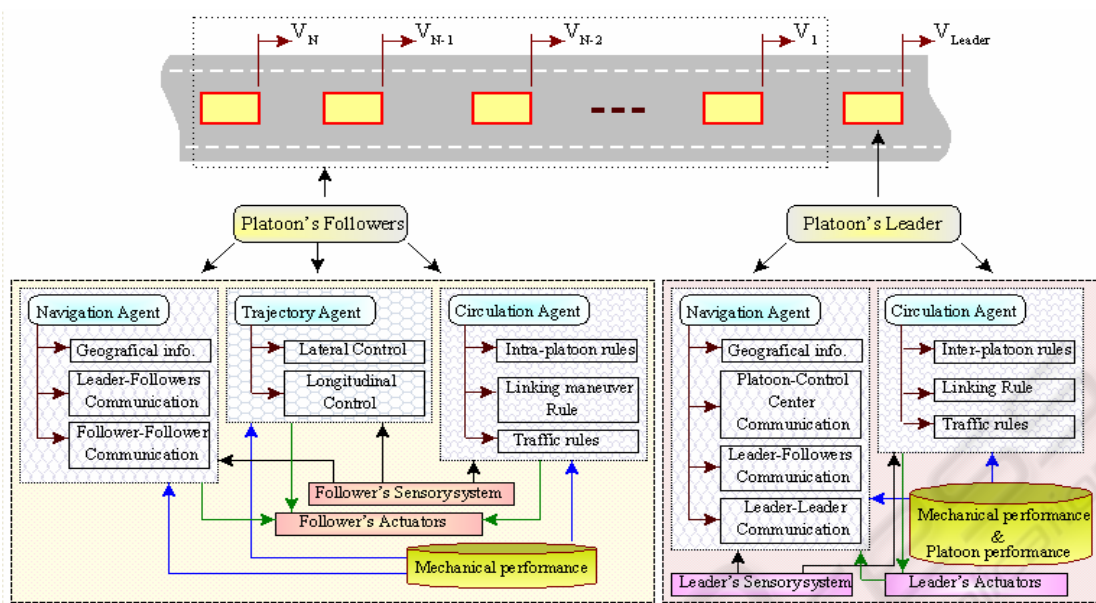


Figure 2: Hierarchical control of semi-autonomous platoon of vehicles using multi-agent system technology.

in order to reach individual stability as well as the string one, without forgetting the platoon units manoeuvres (splitting, merging and following). In addition, the leader as well as the followers requires information related to the mechanical characteristics of each unit, supposing that its size can condition the route and the convoy following, especially in nonlinear trajectories. This kind of information has been called mechanical performance as seen in figure 2.

### 3 AGENT STRUCTURE

The approach used here for the agent design, suggests that its intelligent behavior can be generated by giving it the minimum symbolic representation of its environment, in which these symbolic representations are first order logical formula or/and mathematical formula in the trajectory generation case; lateral control execution level and longitudinal one. In addition, the decision making is implemented in some form of direct mapping from situation to action. That is to say, the decision function action is realized through a set of behaviors, together with an inhibition relation holding between these behaviors.

In this way, the agent's behavior is determined by the agent's deduction rules (its "program") and the environment mathematical modeling (Awawdeh A.M.H et al, 2004-b). For that, agent architecture

has been developed using a composition of three ones: logic based; reactive and layered, as seen in figure 3.

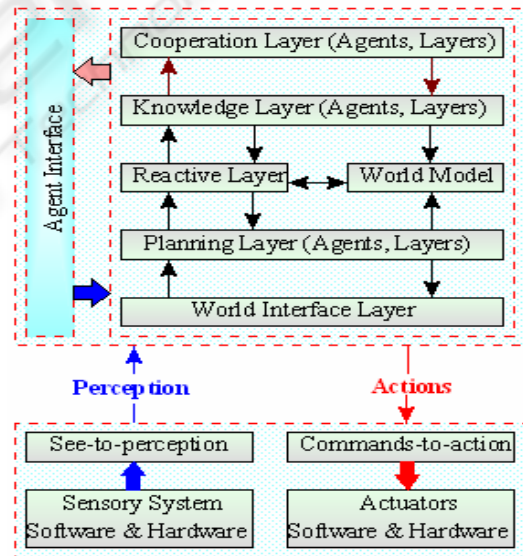


Figure 3: Hierarchical architecture for trajectory; navigation; and circulation agents designed for COVE project.

*Cooperation layer (agent, layers)* - deals with the social interactions, i.e. , the rules that control and "draw" the layer-to-layer, agent-to-agent interactions, intra-platoon cooperation in the follower's circulation agent and inter-platoon cooperation in the leader's circulation agent.

*Knowledge layer (agent, layers)* - deals with the representation of the agent and its environment at different levels of abstraction. In this way the knowledge base is divided to three levels: highest level represents the plans and actions of other agents in the environment; the middle-level represents the plans and actions of the agent itself; and the lowest level represents “raw” information about the vehicle and its environment.

*Reactive layer* - provides a possible immediate response to the changes that occur in the environment. It is implemented as a set of situation-action rules.

*World model*- represents the relation between perceptions and actions. In trajectory agent case, lateral and longitudinal control which are presented as a mathematical model; in navigation agent case it presents the mathematical model of trajectory generation adapted to the curvature. Finally, in the circulation agent it presents the logical model of the traffic rules, inter-platoon, intra-platoon and linking rule.

*Planning layer (agent, layers)* – in the leader’s and follower’s agents, it is responsible for determining the agent goals and for the layers tasks allocation. In addition, in a leader’s circulation agent, it is responsible of the platoon formation plan with other vehicles using the linking rules and of the platoon performance information. Then, according to this information, it plans split or merge tasks.

*See-to-perception*- represents the output of the see function which is implemented in hardware and software to obtain information about the vehicle and agents environment. This perception is the transformation of low-level raw sensor data into higher-level (processed data) in order to make them

suitable for further processing by the navigation and trajectory functions.

*Commands-to-action* – uses hardware and software actuators (traction, steering, notification signals, etc) to transform the agent commands to percept action in its environment.

Finally, this architecture has been used to design the leader agents and the follower agents. The differences here among agents are the tasks of the agent's layers, as indicated before.

To study and evaluate the behavior of the proposed multi-agent system architecture, a simulator with graphical-user-interface has been designed to demonstrate a platoon of vehicles guidance using MAS (Awawdeh, A.M.H., et al., 2004-b). In addition, each agent’s behaviors and actions have been designed as an individual program that can be enabled/disable or active/inactive. These agents are active depending on the operation mode (platoon or free vehicle) and in the platoon case on the members’ driving mode (full-automatic for followers; and manual for platoon’s leader).

Figure 4 presents the block-diagram of communication among agents, data base and designed GUI. The communication is carrying up through the global data base. Imagine that an agent (i.e. trajectory agent) needs information from another one (i.e. Navigation agent), the first send a request message to navigation agent, the last one claims the access to the database, once it is accepted the navigation agent emits the data to the database and sends an acknowledgment to the trajectory agent. The access control program allows the trajectory agent to copy this data once this agent has the priority.

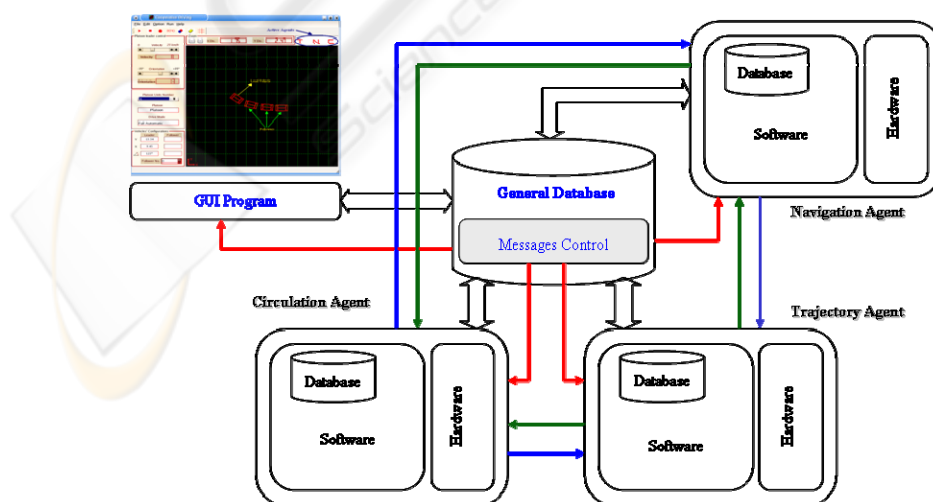


Figure 4: In-vehicle agents interactions and communications.

The algorithms and strategies designed by COVE project group have been validated by means of simulation tools (QT, Matlab, Simulink, and Toolboxes), emulation, and laboratory tests. Using the mentioned MAS architecture the computational time was reduced to 30% of the time required without this method.

As seen in figure 4, each agent has two parts: hardware which represents the associated sensors and actuators, and software part deals with the agent actions and behaviours.

#### 4 NEW PROPOSAL OF HARDWARE IMPLEMENTATION

Communication and control represent the mainly important tasks to address in the hardware implementation of vehicles prototypes for cooperative driving, especially for platoon guidance. The first experimental test was carried out using ad-hoc mobile platforms (i.e. ad-hoc electrical vehicles prototype designed in the Electronics Department of Alcalá University, as shown in figure 5) (Awawdeh, A.M.H., et al., 2005). The low and high level control tasks are executed in a digital system based on PC. For the communication among transport units a commercial Bluetooth module (Module class 1, Conceptonic Bluetooth USB Adapte, CBT 100U) is used.

Figure 6 shows the first hardware solution implemented using personal computer architecture (Pentium II), with external CPLD cards as interface with power electronic cards. On the other hand, the Bluetooth communication technology presents various limitations, such as: reach distance 100m, the maximum number of network's nodes is 8 (1 master and 7 slaves). On the other hand, in the 'piconet' communication mode the master is the necessary link among the followers communication, etc.

These handicaps have been overcome with a new proposal of hardware implementation based on a 32 bit microcontroller -  $\mu$ C - (AT91SAM7S256) and a transceiver (nRF2401A). This low cost electronic solution achieves a high integration level and improves the facilities of the mentioned prototype version.

The Atmel AT91SAM7S256 (Atmel) is an ARM7TDMI based High-performance 32-bit RISC  $\mu$ C that includes: USB device interface, real-time clock and clock generator, 4-channel PWM, 2 wire

interface, 8-channel 10-bit ADC, 256K bytes Flash, 64K bytes SRAM, high-density 16-bit instruction set, IEEE 1149.1 JTAG boundary scan on all digital pins. This  $\mu$ C supports a flexible Real-Time Operating System (ARTX-ARM) including: multitasking (which allows to manage several jobs or tasks on a single CPU), Real-Time Control (which allows to configure tasks so that operations execute within a defined period of time), and Inter-Task Communication (which allows to configure communication between various tasks in the system).

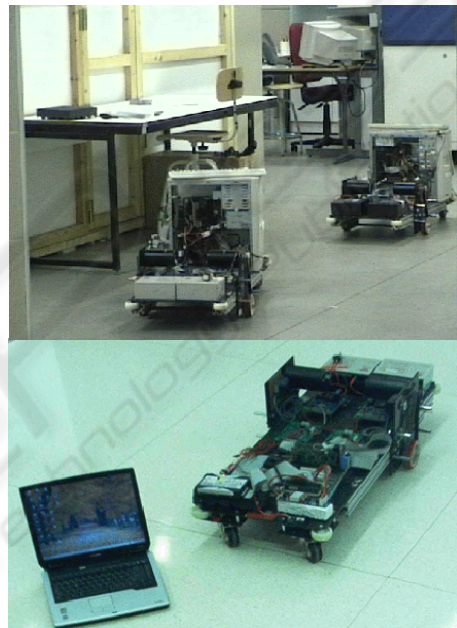


Figure 5: First COVE Platform, based on PC hardware architecture, used as prototype for platoon formation.

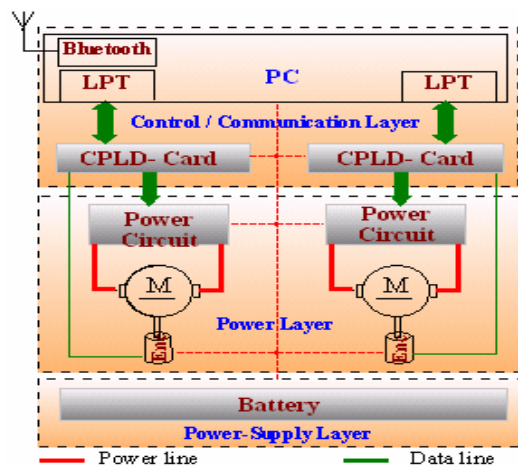


Figure 6: Block-diagram of the first hardware architecture of COVE platform.

Another important device in this new electronic solution for each unit platform of the convoy is the nRF2401A, a RF transceiver highly integrated for wireless communication. The entire transceiver including all inductors and filters is integrated in a single chip; the only external components needed to make a complete RF system are a crystal and a resistor. All configuration of the nRF2401A (Spark) transceiver is done via a standard serial interface. It can receive on 2 channels simultaneously. This module allows to increase the communication range to 2km at least.

Figure 7 shows the most important tasks developed by the  $\mu$ C concerning to the mobile control.

Thanks to the size and weight reduction of the hardware architecture a new follower version is used in COVE project (see Figure 8 and compare with Figure 5).

The used vehicle prototype corresponds to Ackerman structure type. For that, in the controllers design the simplified model (bicycle model) has been used (Matsui, et al., 2000; Maziar, E., et al., 2004).

## 5 CONCLUSIONS

As mentioned before, control and communication are the most important problems to solve related to cooperative driving necessary for platooning applications.

In this work, an improved version of electronics architecture developed for the COVE project is presented. The heart of this proposal is a 32 bit microcontroller (T91SAM7S256), running a multitasking RTOS. In this way the multi-agent system designed by the research group is implemented avoiding the use of PC as in the previous versions. Besides, a transceiver (nRF2401A) makes easy the wireless communication among followers and leader, and increase the network node-spacing distance.

## ACKNOWLEDGEMENTS

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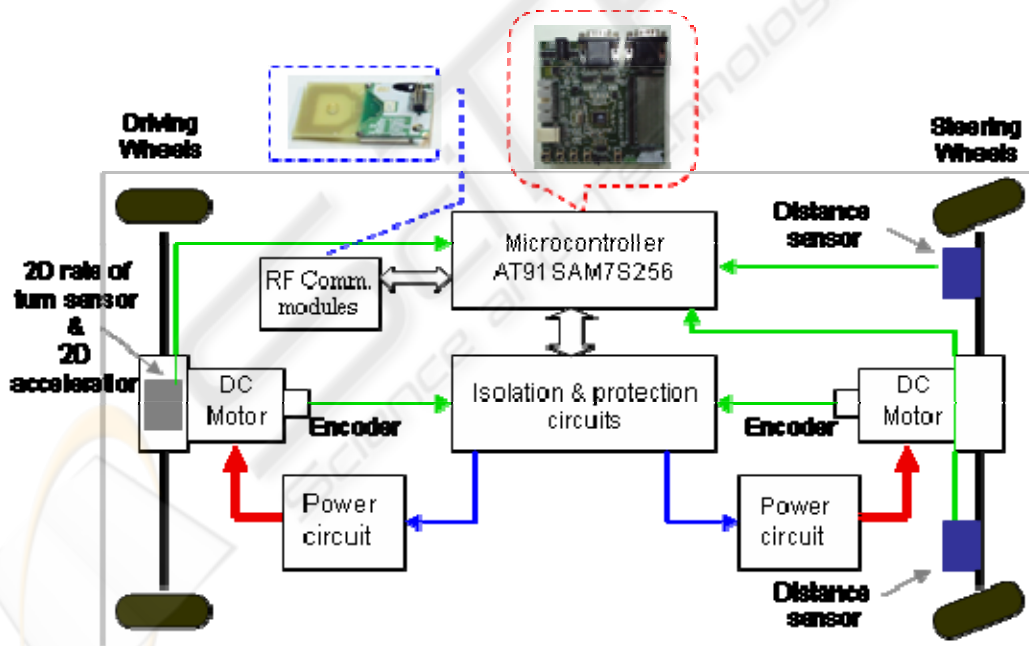


Figure 7: Scheme with the main signals involved in car-like mobile prototype control based on the AT91SAM7S256 micro-controller.



Figure 8: Two sides of the new mobile prototype for platooning guidance used in COVE project.



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