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STATE OF THE ART IN MOBILE SYSTEMS' ENERGY MANAGEMENT AND EMBEDDED SOLUTIONS FOR IMPROVING THE ENERGY EFFICIENCY

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Abstract: *The present paper presents a state of the art for the mobile devices' energy management and a possible design for a new embedded control system used in this domain. The main goal is to make a study about the technology used in this field and to design a new concept, better than the ones that already exist. Thus, the designed control embedded system has to improve the fuel consumption, the viability and the availability of the mobile systems, has to be scalable and auto-adaptive and has to use sensor networks and embedded computers.*

Key words: *control, embedded system, energy management, alternative energy, super capacitors.*

1. Introduction

Nowadays, we are totally dependent on an abundant supply of energy for living and working and that's why, energy is a key ingredient in all sectors of the modern economies and it is fundamental to the quality of our life [12].

Also, the issue of global warming and CO_2 emissions it is continuously researched. In order to abase the global increasing temperature phenomenon, the CO_2 emissions have to be reduced.

Thus, the fuel consumption reduction, the energy efficiency and the renewable sources became important goals that need to be assessed.

The micro-electronics, telecommunications and information development have lead to the improvement of the acquisition systems' management.

The control process dedicated to the energetically field is related to the equipments involved in the technological flow.

The majority of the vehicles use the lead-acid (L-A) batteries as power supply for the starting process of ICE (Internal Combustion Engine). After the starting process is made, it provides the necessary amount of electric energy for the vehicles' movement [2].

The biggest problem is that the starting process requests from the batteries an important amount of current (power) which affects the life time of the battery.

The goal is to design a fully integrated, scalable and adaptive system able to control a mobile device and thus to increase the life-time of the battery and

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to reduce the power consumption, the fuel consumption and the pollution.

Depending on the application, the energy consumption and the pollution can be reduced by using adequate software or hardware techniques or by combining them in an embedded system.

The present paper describes a state of the art in the mobile systems' energy management and a solution for an intelligent system. The embedded system has to have the intelligence to efficiently assure the energy management for a mobile system which can belong to the biomedical field, robotics or automotive.

For example, in applications like automotive or robotics, the components connected to the control embedded system can be the alternator, the starter, the super-capacitor, the battery, the ICE (Internal Combustion Engine), the photovoltaic Cells (PV Cells) and the additionally loads. The embedded system has to monitor them. Also, the control system has to have intelligence to take real time and optimally decisions in the supplying and in the charging process and have to control the storage elements and all the devices involved in this process.

Thus, the improvement of the vehicle's efficiency can be done with this embedded control system able to monitor the supplying and the storage devices.

2. Research Project Description

The main goal of the project is fuel consumption optimization of a mobile device, the viability and availability improvement by developing an embedded system which is based on systems with microprocessors and sensor networks.

The reduction of the power consumption in the ***mobile devices*** can be made by using adequate hardware with low power consumption and by implementing an intelligent scheduling algorithm that commands the acquisition, the pre-processing phase and the reliable data transmission.

In ***automotive***, the developed solution will be fully integrated onto the mobile device and will communicate with the board computer by using the specific protocol of its.

The *start/stop process* of the mobile device will be intelligently and efficiently controlled and it will use the stored energy onto the super capacitors and/or onto the battery. The auxiliary loads will be supplied from the super capacitor, too.

The energy sources' control strategies are improved by correlating them with the mobile system and with the board computer.

The electronic device has to be able to control the energetically flows, the ICE (Internal Combustion Engine), the starter, the generator, the photovoltaic cells, the super capacitor, the battery and the ancillary loads.

This system will improve the power and fuel consumption of the mobile devices by interrupting the engine's functionality when the mobile system is stationed and by automatically restarting the engine, in a short period of time, when the driver wants to accelerate.

Also, the system will permit the loads' supply smoothing by using the super capacitor as load buffer. Thus, the ancillary loads will be automatically switched onto the super capacitor (air conditioning, lights, wire/wireless communications, multimedia, vehicle to vehicle communications (V2V), and vehicle to infrastructure (V2I) communications).

We will focus on designing the mobile devices' energetically flow control system with low costs in order to assure the start/stop process, the improvement of the battery's life cycle, the improvement of the fuel consumption and the reduction of the pollution.

The same start/stop process can be developed and adapted to the ***robotic field*** in order to increase the battery's life time of the robots.

3. State of the Art and Existing Problems

A statistic shows that in 2003, the transportation sector (including land, sea and air transportation) was responsible for 24% of the global emissions of the CO_2 [4].

The same statistic affirms that cars represented 10% of the cause for the global CO_2 emissions.

Because of the mobility needs, portable devices, wearable devices and vehicles are more and more used in daily activities.

Thus, if we take in consideration the ***biomedical wearable devices***, the need of autonomy became a necessity.

In general, medical portable monitoring systems are used to collect data for offline processing but these data could not be used for real time detecting of the illness or of the dangerous situations.

In 2002, a study made by the researchers from the University of Karlsruhe ended with an application of a portable computing technology in health monitoring systems which was published in Biomedizinische Technik [9], [15]. The conclusions of the study after implementing an experimental system proved the significant reduction of cost when using portable computing equipment along with miniature intelligent sensors instead of traditional medical devices [9].

In 2004, a team from the department of electrical engineering from the National University of Taiwan presented in IEEE Trans. Inf. Technol. Biomed. a mobile monitoring system that integrates portable computing devices such as SP/PDA for electrocardiography signals [11]. The designed system is only for hospital indoor use, but it shows advantages compared to classical heart monitors [7].

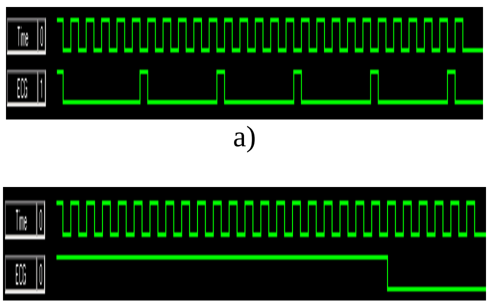
In all these studies presented above, the problem that appears because of the wearable devices which have to assure the mobility of the patient is the battery's autonomy.

And thus, using a portable device in ambulatory it is not a complete solution for patient's monitoring unless the energetically management it is developed, thus to drastically reduce the power consumption.

The batteries have a reduced number of life cycles. Damaging the batteries involves supplementary costs to replace them and also other costs to recycle them. Thus, this aspect is not in accordance with the actual "green regulations" that give as mandatory the reduction of lead usage in order to decrease the pollution rate of the environment (lead free).

In order to abase the power consumption, low power consumption hardware components were used and a scheduling algorithm was implemented in the embedded system's firmware [9].

The schedule of an ECG (Electrocardio-graphic) monitoring process it is represented in Figure 1.



a)

b)

Fig. 1. *Time schedule for ECG monitoring* (*on the abscise axis time is given in minutes 1 cycle = 4 minutes*) [6]: a) *Monitoring schedule for normal status;* b) *Monitoring schedule for alert or/and emergency status*

The mobile tele-monitoring system is focused on three different situations: *daily monitoring* (normal situations) - when the patient has a stable status or “normal status”-, *alerts*- when the monitored parameters excels the normal threshold- and *emergency*- a status that requires medical intervention.

By implementing a scheduling algorithm on the embedded system the energy management it is improved and the power consumption is reduced from 10 mA/3.7 V to less than 1 mA/3.7 V [6].

Reducing the fuel consumption and pollution became a major challenge to the ***automotive industry*** too. The environmental regulations have forced the automotive industry to research for alternative solutions.

After a couple of statistics on the automotive field, it has been established that the stopping periods in the urban traffic represent 35% of the total driving time. This means that a big amount of fuel combustion is wasted along the time. A method to reduce the fuel consumption when the car is not moving is to stop the engine through this period.

In consequence, if the start/stop process is developed, the atmospheric and sound pollution would be reduced, the driving comfort would be increased and the fuel consumption would be reduced as well by 12%, as a study made from the Green Car Congress affirms [13]. Unfortunately, this action would drastically reduce the battery’s life time if the battery is the only electrical energy source existing on the cars.

Thus, we have thought to a smart control embedded system able to allow the stopping of the engine when braking and automatically restarting it when the brake pedal is released.

In the studies made so far on the electric vehicles, the primary source of energy is the battery. Also, an electric motor is present to assure the vehicle’s propulsion. The battery of the electric vehicle needs to be charged from an external device and that’s why a suitable monitoring and charging control system for the battery has to be implemented.

The mild, micro hybrid vehicles or electrical vehicles became a field of interest because of the fuel consumption and pollution of the nowadays cars.

University of Hong Kong affirms that hybrid vehicles operates on both electric motor and petrol engine and are 50% more energy efficient and have 50% fewer polluting emissions thus minimizing the threat of global warming [14].

The Chinese University of Hong Kong developed a system used on hybrid vehicles designed to reduce the power consumption [11].

The problem related to the peak of current consumption in the starting process has not been solved yet by the Chinese University of Hong Kong because the starting process takes a big amount of current from the battery and that’s why the battery’s life time it is dramatically reduced.

Our solution comes to improve the life time of the battery by using some additional alternative storage units with quick response in time represented by the super capacitors. The difference from other implementations is that the restarting process is supplied from the super capacitor thus protecting the battery and improving its life time.

The researches made in the last years in super capacitors field have determined the apparition of some super capacitors that become more appropriate to fulfil the requirements related to the maximum current, power density and energy density needed in automotive [2].

The necessity of implementing a complete embedded device that can be used to optimally manage and control the fuel and energy consumption became mandatory.

The control system it will be designed fully embedded, and will be able to communicate with many devices through Bluetooth, USART, CAN, I2C interfaces and so on. The system's architecture is presented in Figure 2.

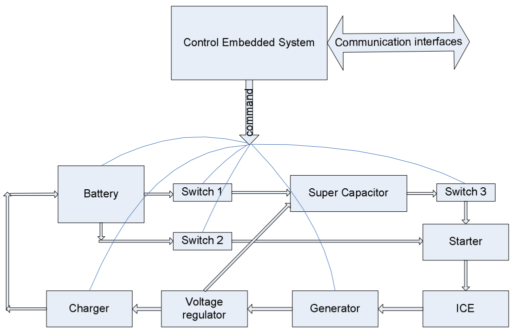


Fig. 2. *The control system's flow*

4. Energy Management - Batteries, Super-Capacitors and Fuel Cells

Energy storage devices are the key components from a mobile device.

According to ADEME (French Environment and Energy Management Action), the conservation of our health and the conservation of the environment are very important aspects that have to be taken in consideration when designing an embedded solution for energy sources' management and control [10]. The production and also the consumption of the energy have a big impact on the local environment.

The idea of developing an embedded system able to control the storage elements and the recharging process became mandatory if we consider that implementing this will decrease the carbon dioxide emissions. For example, a study made in France by ADEME has shown that 35% of CO_2 emissions came from the transport sector [10].

Another study, made by the Green Car Congress in 2006 shows that the transport sector from Australia, for example, contributed with 79.1 Mt CO_2e (13.7%) at the gas emissions [13].

The same study shows that road transport was responsible for 87% of the emissions or 12% of Australia's total emissions and the gas emissions have been increasing at an average of 1.7% per year since 1990.

In Figure 3 the existing and the proposed international greenhouse emission targets for passenger vehicles are presented.

The new European drive cycle (NEDC) enforces the conversion of the all standards to gCO_2/km. The EU assumes a 120 g/km achievement. The California line is doted, pending go-ahead [13].

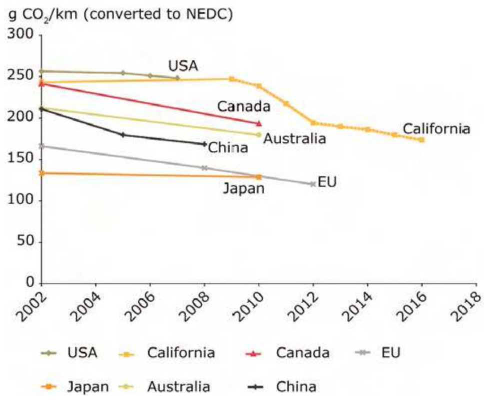


Fig. 3. *Greenhouse emission targets for passenger vehicles* [13]

Taking into consideration all the factors presented above, the embedded control system it will be developed in order to increase the energy efficiency and thus, the mobile devices (vehicle, robots) will become less polluting.

Decreasing fossil fuel consumption and expanding the use of the renewable energy sources are helping to reduce the emissions in the environment [10].

Batteries are common ways for energy storage [3]. In present, the protection of the environment became a serious problem that we have to look at and the researches are made on how to increase the battery's life time.

Thus, the battery management system has to increase the battery's life-cycle and has to assure a good functioning of the battery by inspecting and estimating its State of Charge (SoC).

SoC is defined as the percentage of the battery's full capacity that is still available for further discharge [1].

In order to increase the battery's life-cycle we have used a super capacitor as an intermediate buffer for energy in order to reduce the voltage cycling amplitude for the batteries.

The control system it will be designed to optimally supervise the charging process from different sources and to control the energy distribution in the mobile system.

Mobile systems can also be equipped with photovoltaic cells (PV cells) in order to increase the amount of energy which supplies the battery and/or the super capacitor.

Photovoltaic cells work by transforming the photon energy in solar radiation directly into electrical energy without an intermediate mechanical or thermal process [12]. PV cells operate on the principle that electricity will flow between two different semiconductors when they are put in contact with each other and exposed to light. By connecting a number of these PV cells together a flow of electricity can be achieved.

Thus, by the help of the control embedded system, the storage elements (battery, super capacitors) can be supplied from the ICE or by using alternative power supplies like PV cells. The control system will determine the statuses for the energy sources and for the storage elements and will automatically commute on the optimal power supply in order to charge the storage device.

By linking power management systems and control systems allows the power information to flow through both systems [8].

Load profiles can be developed to find any energy inefficiencies.

Energy scheduling can be used to find the optimum energy schedule for new product lines or processes [5].

Reducing the energy consumption can be managed in a *static or a dynamic context*.

For example, an application of the static context can be the stating process of the mobile device. The embedded system automatically commands the start of the engine from the super capacitor, thus reducing the energy consumption and increasing the life time of the battery.

As a dynamic application, being monitored by the embedded control system and depending on the status of the mobile device, the super capacitor and battery can be both charged from the engine and/or from the PV cell.

Because a lot of kinetic energy is wasted into heat during braking periods, decelerations periods and descending periods, the embedded system is also designed in order to control the power flow from sources to the intermediate buffer, in our case the storage elements (super capacitors) that have to be charged from the electric motor, operating in the generator mode. Vice versa, in case of the power request from the electrical motor in the first instance this will be provided from the storage device and afterward from the batteries under the control of the embedded system. Such a control law does not involve supplementary fuel consumption.

By acquiring real time data from the storage devices and supplying systems through the sensors network, the smart embedded system can command the supplementary loads from the vehicle to be supplied from the super capacitor. Thus, the fuel consumption and the emissions are reduced and the battery's life cycle is increased.

For example, while running, the super capacitor can be continuously supplied from the ICE and/or from the PV cells as is presented in Figure 4. Thus, it can assure the supplying process for the auxiliary loads of the vehicle.

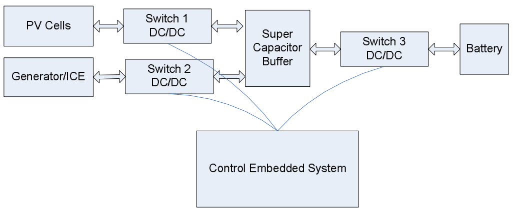


Fig. 4. *The supplying process from super capacitor and from PV Cell*

A statistic made on Citroen C4 shows that the fuel consumption is increased with 1 L/100 km while the air conditioning (AC) is switched on in a vehicle. At the idle speed, the fuel consumption is increased with 0.2 L/h when the air conditioning is turned on.

If we consider that a vehicle is staying 10 times a day at a semaphore, for 3 minutes each, with the air conditioning turned on, the supplementary fuel consumption due to the AC is increased with 0.1 L. By making a simple estimation, in a year, the fuel consumption of a car is increased with 36.5 L.

The same problem appears with the communications devices of the vehicle. For example, the embedded system can be adapted and can assure a good functioning of the V2V communication or can commute between the storage sources in order to find the optimally one to supply the wire/wireless communications inside the vehicle.

Because the starting process of a robot needs a big amount of energy, the above presented starting process from the super capacitor can be adapted to the *robotics field* too. This peak of power affects the life time of the battery, as in the vehicle's starting process case. Thus, by placing a super capacitor onto the robot, the embedded system will be able to commute the starting process onto the super capacitor and after the starting was made, the functionality of the robot will be commuted by the smart embedded system back onto the battery.

5. Conclusions and Future Work

The mobility need enforce us to research about how to reduce the energy and fuel consumption.

The described embedded system has to be developed in order to assure high efficiency for the control charging process of the storage devices (battery, super capacitor) from different power supplies (PV cells, ICE). The system has to have the intelligence to permanently verify the status of the storage devices. Thus, by acquiring real time data from the supplying and storage devices, the system will be able to command the charging process from the optimally power supply.

The smart embedded system is fully integrated, is modular (in order to assure high security), is scalable and is auto-adaptable. The auto-adaptability process it will be assured by implementing the correct firmware.

The biggest advantage of the described system is that it offers the possibility to correctly use the alternative power supplies and thus it helps to reduce the fuel consumption and the pollution.

The embedded system contributes at the "green" concept by controlling the functioning process of the mobile device and orienting the starting process from the super capacitor thus increasing the battery's life time. The starting process is made from a "stacked" super capacitor, because, some of the biggest advantages of its are: it does not pollute the environment because it uses water-based electrolytes; it has a good cycle and provides good mechanical resistance.

The advantages presented above made us to think about using this device in our energy management system in order to reduce the pollution, to increase the battery's life cycle and to improve the fuel consumption.

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