UNIONE EUROPEA

Ministero dell'Istruzione dell'Università e Ricerca

UNIVERSITÀ DEGLI STUDI DI SALERNO

DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

Dottorato di Ricerca in Ingegneria Meccanica
X Ciclo N.S. (2008-2011)

"Models for design and control of a solar-hybrid vehicle with a tracking solar roof"

ABSTRACT

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ABSTRACT

Our planet faces significant challenges in the twenty-first century because energy consumption is expected to double globally during the first half of this century. Faced with increasingly constrained oil supplies, humanity must look to other sources of energy, such as solar, to help us meet the growing energy demand.

A useful measure of the level of a country's development is through its energy consumption and efficiency. Excessive fossil fuel energy use not only has caused severe and growing damage to the environment from greenhouse gas emissions and oil spills, but also has brought political crises to countries in the form of global resource conflicts and food shortages.

Solar and other forms of renewable energy offer a practical, clean, and viable solution to meet our planet's growing environmental and energy challenges.

Solar radiation is the most important natural energy resource because it is a renewable, free and largely diffused source. The Sun provides the Earth with an enormous amount of energy.

Naturally, the Sun has always held the attention of humanity and been the subject of worship by many cultures over the millennia, such as the Egyptians, Incans, Greeks, and Mayans, among many others. The potential of solar energy to produce heat and electricity to be supplied for our modern economies in a variety of productive activities has been widely demonstrated but not yet widely adopted around the globe due to relatively cheap fossil fuels. The main problem of this kind of energy source is that it is not constant during the day and not readily dispatched. In contrast, modern lifestyles demand a continuous and reliable supply of energy. However, there are ways to overcome these shortfalls.

In chapter 1 there is a general presentation of solar irradiance and the main solar angles: global solar irradiance is composed by diffuse, reflected and direct radiation. To direct radiation the geometrical relationship between the Sun and the Earth must be known. Nowadays solar technologies are involved to industrial maturity: to capture solar energy as much as possible firstly arrays with an optimal fixed tilt have been developed, then solar tracking arrays.

For many of reasons, especially energetic, environmental, economic, a big interest nowadays has been developed for hybrid vehicles, particularly hybrid electric vehicles HEV; *but* in recent years HSV are attracting increasing interest. The last ones use solar energy. These kind of vehicles are described in chapter 2.

It must be underlined that there is a great difference between hybrid solar vehicles and solar cars: in fact solar cars now do not represent a realistic alternative for traditional cars, because they depend only on sun availability and have high costs. Instead HSV do not have problems concerning the autonomy range, because they have an electric motor and also a traditional combustion engine.

However until now in literature a little interest has been given to the hybrid solar vehicles despite HEV but at the University of Salerno a prototype of HSV has been developed and another one is going to be developed.

Formulating the control algorithm for determining the fuel efficient power split between two energy sources is referred to as the supervisory control or energy management problem. In chapter 3, the main control strategies, used also for the energy management of HEV, are examined. Control strategies may be classified into non-causal and causal controllers respectively. Furthermore, a second classification can be made among heuristic, optimal and sub-optimal controllers.

Great importance has given to three different strategies: Dynamic Programming DP, Genetic Algorithm GA and Rule–Based strategy RB. For each one the techniques of optimizations are described.

An HSV vehicle has been modeled, and for this model especially RB strategy and GA optimization have been applied to see the most convenient one to apply on HSV prototype

developed at University of Salerno. So a comparison of RB strategy with the other two is shown, and its advantages and facilities are described through experimental data.

In chapter 3 this comparison shows that the adoption the results obtained by the optimization through RB strategy are close to the ones obtained with the other two optimizations. So this strategy seems convenient for two main reasons:

- the previous knowledge of the driving cycle is not always required;
- there are not strict mathematical operations.

For these reasons RB strategy has been applied: it has been shown that it is necessary to compute the mean value of power traction and to establish the value of the sun factor.

$\bar{P}_{tr}$ can be evaluated with a backward or forward strategy:

- **Backward:** the mean value is evaluated on the previous knowledge of the data, taking the mean value of the power during a certain period;
- **Forward:** the mean value of the power is predicted.

In chapter 4 numeric and experimental results about the application of this optimization strategy have been shown. First of all fuel consumption has been computed through a program developed in MATLAB, taking driving cycle from literature: it has been demonstrated that the values of fuel consumptions computed with backward and forward strategies of power traction are not very different. Then, through experimental tests, the adoption of on-board solar energy prediction is presented and there is also the demonstration of the beneficial to select the best solution in terms of energy management.

Finally the program, previously developed for a generic HSV, has been adapted to the HSV prototype developed at University of Salerno considering also experimental driving cycles: the validation of Rule–Based strategy applied on the HSV prototype is presented through experimental tests. After it has been decided to adopt RB strategy for the on- board energy management of the HSV prototype through the adaptation of the MATLAB program into a program developed in LabVIEW.

In chapter 5 a moving solar roof for an Hybrid Solar Vehicle is presented, and differences between a tracking system for mobile and fixed applications are underlined.

With an optimal orientation of the roof, that means when the angle of incidence between the normal to the roof and the sun ray tends to zero, there is a considerable gain of energy.

The mobile solar roof has been realized as a parallel robot with three degrees of freedom. A mathematical model has been developed in MATLAB, the design has been realized through the software 3D SolidWorks, the control system had been realized at the beginning with a PLC, then with a webcam placed in the middle of the mobile roof and the control has been developed through a program realized in LabVIEW.

The model of the proposed roof has been developed and validated over experimental data obtained by a small scale real prototype. The kinematic model presented has allowed the optimization of roof geometry and shape. The best orienting properties are reached with shapes approaching a circular one, and with the minimum distance between globular joints. The optimal solution has been determined by an integrated analysis of both roof and vehicle shape.

The economic feasibility of this project but especially the energetic gain has been evaluated: this model has been designed to be mobile only during parking phases for two main reasons:

- The HSV analyzed must be used only for a **urban use**, so the driving phase lasts only 1-2 hours and the largest part of the day is a parking phase;
- If the solar roof is mobile also during the driving phase some **aerodynamic losses and instabilities** could happen.

The adoption of a moving solar roof for vehicle applications can substantially enhance the energy recovered during parking phases, for a solar electric or hybrid vehicle. Moreover, this system can result particularly useful at high latitudes, where an horizontal panel would be strongly penalized by low sun height. The adoption of a moving roof can therefore extend the potential market of solar assisted vehicles.

In order to maximize benefits of the mobile solar roof, the energy consumption related to its movement must be minimized, and unnecessary movements avoided. To this end, a control procedure based on the use of insulation data provided by the solar panel, information derived by a GPS module and by processing the sky images taken by a webcam has been presented. The webcam has been placed in the middle of the mobile platform of the prototype, it makes a picture of the sky; in this picture two points are signed: the center of the picture and the center of mass of the points with maximum brightness. The main idea is that the center of the picture tends to go on the center of mass of the points of maximum brightness. Through this control system it has been also valuated the best interval between two different orientations, and the result is that during the day the interval between two different orientation changes, and it is convenient to orient the roof in the middle of each intervals, that means that if it has been computed that the best interval at 9.00 a.m. is one hour, there is a bigger gain of solar energy if the roof is oriented at 9.00 a.m. with the best orientation of 9.30 a.m. until 10a.m. and so on.