Design of a Robot Photovoltaic Power Supply System

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Abstract: - It is desirable that robots would be, as much as possible, autonomous and self-sufficient. This requires that they can perform their duties while maintaining enough energy to operate. On this regard this paper presents the design and initial results for the power supply of an autonomous robot. Actually Robot design is divided into four primary areas: energy storage, actuation, power and control. But of course there are many relationships among these phases so as matter of fact they have to be made in parallel to optimize the robot especially energetically. In particular a power supply solution that utilizes solar cells and a microcontroller have been chosen to power and control the robot. Finally, initial tests with a probe-loaded robot prototype have demonstrated the feasibility of the solution.

Key-Words: - power supply, Photovoltaic system, mobile robot,

1 Introduction

There is a large variety of autonomous robots: these can be classified according to their structure, dimensions, maneuverability, main tasks, and so on.

In any case, every robot requires a power source to make all its functions, like mobility, control, measures, to mane just the most important.

So we have seen that in most cases, robots have a storage system that self-recharges during the mission or at the beginning of the mission, by power stations.

This solution increases the robot weight and consumptions, then we are here exploring about the added value, in terms of increased autonomy, of an autonomous power source installed on the robot.

In particular, we concentrated our attention on the photocell technology (increase of efficiencies) that cheap (decrease of cost for Wp), as well as on the possibility to use cells on the flexible support, increasing the adaptability degree at any surface of every form.

The paper is organised as follows: the state of the art of the photocell application in the robots will be first presented; then a description of the robot and its energy characteristic will be given; subsequently a description of the project of an autonomous photocell system to apply on the robot will be discussed.

So far batteries and/or capacitors are used as power sources.

The battery supplies only a DC voltage used for the control board of a robot; the capacitor supplies AC voltage for the control of the mobility of a robot by electrical servomotors.

The battery uses more time than the capacitors to charge and to discharge energy.

There are two strategies for recharging batteries and capacitors: solar panels on the robot and power stations. Gary B. Parker and Richard S. Zbeda [1][2] explain how to power and control the hexapod robot Servobot.

Matt Lister and Thomas Salem [3] deal with the DC battery system, since it is the main power source for the robot. Normally this system consists of a combination of switched mode DC power converters. Experimental results show the converter efficiency and voltage ripple at rated load. A discussion of lessons leamed provide insight into the need for proper component selection and placement, printed circuit board fabrication, and ensuring a proper ground plane for successful implementation of a switched mode DC power converter.

Albert Esser and Hans-Cristoph Skudenly [4] explain a new system to supply energy for multilink robots.

It contains rotatable transformers placed in their joints, thus avoiding the use of movable cables.

Mitsuteru Rimura, Nobuki Miyakoshi and Mesahiro Daibou [5] explain a miniature opto-electric transformer, consisting of a p-n junction photocell and a multilayer spiral coil transformer monolithically fabricated on a silicon substrate. It converts the optic energy, acquired from a photocell, into voltage.

Andrè Colens [6] explains a system for resupplying power to self-contained mobile equipment, including a fixed station having a external power source and consisting of a high-frequency generator and an induction coil as well as, on or in the equipment, a pick-up coil, a current filtering and rectifying device, a rechargeable battery pack and a microcomputer-controlled tracking system.

Sergio Hernàndez, Carlos A. Morales, Jesùs M. Torres and Leopoldo Acosta [7][8] deal with mobile robots for the localization by means of a transmitter-receiver system positioned on the robot and on a fixed point in the environment.

The transmitter is based on a red IIIA laser and the receiver is a cylinder having thirty-two photocells. The position and the orientation of the robot are obtained when the laser hits every photocell.

2. PV system sizing problem

Solar energy harvesting has become increasingly important as a way to improve lifetime and reduce maintenance cost of portable appliances and stand alone power systems. In particular the use of this system for supplying systems with limited size and mass but high-power requirements such as a mobile robot is studied.

In this context microrobot are excluded as in this case the PV cells are embedded into the body of the robot [9]

The micro-solar powered designs that have been developed have a specific set of requirements such as: lifetime, simplicity, cost, compactness, reliability and so on.

However all the systems developed operate correctly under a set of conditions while there is not a generic procedure for the optimal sizing of an autonomous energy system that supplies for instance the power needs of the onboard equipment and instruments of a mobile robot.

As far as the power requirements, apart from walking energy requirements that are normally so high energy consuming that the active PV area, using thin or crystalline technologies, is very wide, are concerned, many pieces of information can be taken from the experience of supplying wireless nodes. In [10,11,12] Li-ion batteries and super capacitors are used as charge buffers for alternative power sources. On the other hand batteries are not a recommended power source for robot that has to work in a isolated zone since the power source would limit the lifetime of the system, but it should be remembered that rechargeable batteries are a secondary power sources. Therefore, in the context of robot applications, another primary power source must be used to charge item (as a solar cell).

Other power sources as mechanical vibrations are important as proof of concept but they are not a viable option for cost and reliability [13].

In order to account all the objectives (Lifetime, flexibility, simplicity, cost etc…) the best compromise appears the use of micro solar power system with rechargeable batteries.

As a framework for understanding the operation of a solar-powered micro robot a generic sizing procedure will be adopted and the various design choices, difficulties, tradeoffs, and interplay between each components will be investigated.

The optimal sizing procedure that will be adopted in this project, allows determination of both the optimum power output required from the Solar Cell Array (SCA), and the optimum capacity of the storage system which together would supply electric energy required by the robot, especially for control, sensors and wireless transmission. The objective of the optimization problem is the maximization of the Number of Autonomus Days (NAD) of the system.

The control variables of the optimization problem are:

- the SCA surface (A_c),
- the storage system capacity (B_C)

The optimization process requires the following inputs:

Site: latititude, longitude, height , meteorological data

PV system: PV cells Technology (thin film, monocristallino, poly), PV panel exposition (tilt angle with the horizontal plane and azimuth angle)

Battery: characteristics (Lithium, NiCd,etc…), electrical characteristics (Capacity, voltage),

Load: Components and sensors of the robot, Wireless Communications

The PV panel exposition is not assumed to be a control variable because to obtain the objective of the optimization problem (maximization of the Number of Autonomus Days (NAD) of the system) it is important to meet the worst condition (minimum solar radiation). This conditions are reached in winter and in the same period the best PV panel tilt angle is 90° with the horizontal plane.

However this choice has to answer to a problem of integration with the chassis that contains the components of the robot.

The load demand will vary varying for example: the wireless communication technology (and/or the transmission rate), the components and the management system. The storage system capacity is related with the charge regulator that will vary varying the battery type.

The hourly energy consumption of the system will be computed for different configuration and operation schemes of the robot

In [14] a parametric study on the sizing of PV system with batteries is reported. In this context it gives an idea of the ratings of the main components of a stand alone PV system.

In [14] it has been assumed that the ratio between the active mode operation of sensors and their stand-by (sleep) condition is varying between 1/100 and 1/600, when the acquisition time is varying between 10 and 60 s.

The power consumption of the MCU section is almost constant for the considered operating conditions and it is likely to be 13.8 mWh. At the same way the average energy consumption of the sensors section is assumed to be 4.2 mWh (when acquisition time varies between 10 and 60 s).

To perform the PV system optimal sizing some data have to be fixed. First of all the solar irradiance, in particular the period of time when the worst availability of solar energy has to be considered, but it also depends on the tilt and azimuth angles of the PV panels. In [14] the panel faces south and the tilt angle "β" is 90°, in this case the minimum of the monthly average daily solar radiation in Catania is 9.1 MJ/m^2, and this value has been reported in June. This condition permits to maximize the energy output in the period with lowest insolation (winter).

The solar module choice is a thin film PV panel, for some advantages as easy to assembly, low cost and suitability to large applicationst. The characteristics of the PVS are summarized in Table 1.

Table 1: PVS components characteristics [14]

Parameters	Values
Solar module	Thin-Film
Shading ratio	0.96
Reference module efficiency	0.0438
Array tilt angle	90° S
Battery type	Li-ion
Battery Current [Ah]	2.2
Battery Voltage [V]	3.7
Battery storage efficiency	0.9
DOD	0.9
NAD	5

The optimal sizing procedure has been obtained by varying both the Transmission/Acquisition Time and the communications technologies (GPRS, ZigBee(Z), RF) shortened respectively as: G, Z and R. Related to the various configurations, Table 2 provides the outputs of the optimization procedure, showing the optimal values of SCA surface (Agmin) and related Peak Power (Pg) and the storage system capacity (BC).

Table 2: optimized values of the design variables [14]

Case	A_{gmin} [cm^2]	P_g [Wp]	B_C [Wh]
G10	700	4	45
G20	400	3	24
G30	300	1.5	17
G60	150	0.8	10
Z10	40	0.3	3
Z20	43	0.24	2.8
Z30	38	0.2	2.5
Z60	38	0.2	2.5
R10	43	0.24	2.8
R20	43	0.24	2.78
R30	43	0.24	2.78
R60	43	0.24	2.78

Nowadays there are available on the market advanced triple-junction (ATJ) solar cells, built originally for space applications, that have efficiencies higher than 22%, so they can help to reduce significantly the required PV surface.

3 Robot Design

In this section, we discuss about the mechanical and electronic elements of the autonomous mobile robot developed. In particular, the robot design process and the energy consideration are shown. Typically, robotic machines are employed in two types of environments:

- highly structured (regular) industrial environments where precise, repetitive motions are required;
- unstructured exploratory environments where little knowledge about the terrain is known and the task of the robot is to collect information.

Fixed robotic arms and wheeled robots are employed massively in industrial applications where floors are flat and obstacles are well-defined. When different tasks are taken into consideration, for instance exploratory mission, there are some examples of wheeled systems including several interconnected modules [14]. To deal with complex terrains, useful solutions can be found taking inspiration from nature for mechanical design and locomotion control. Wheels are easy to control, as they act very predictably when running on a well-known surface. Whereas legged robots are, infact, much

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better suited for dealing with unknown environments.

Wheeled vehicles have clear advantages of energetic efficiency on roadways, but the advantages of wheels fade as the uniformity of the terrain degrades, and wheeled vehicles are incapable of dealing with most natural terrains. On the contrary walking vehicles are more robust, in fact the loss of a single leg on multi-legged robot will not imply a dramatic loss in maneuverability. This characteristic is absent in wheeled vehicles, where a damaged wheel could produce the end of mobility, and a damaged track always results in a complete failure. Finally, legged vehicles are more capable of navigating on intermittent substrates such as a shuttered surface than wheeled vehicles. Up to now more than half of the earth's landmass is inaccessible to wheeled vehicles [15]. The same problem is associated to planetary explorations.

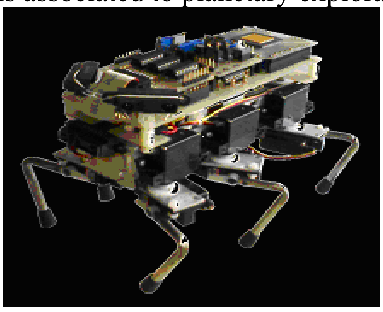


Fig.1: The MiniHex robot. The low level locomotion control is based on the CPG paradigm.

To summarize, legged robots cannot be view as competing with wheeled machines: it is rather complementary and is employed in environments otherwise inaccessible. Moreover to optimize the performance of walking robots it is possible to take inspiration from nature and in particular the biological principles governing locomotion in insects. Fig.1 shows an example of bio-inspired mini robot based of the Central Pattern Generator (CPG) for low level locomotion control [16].

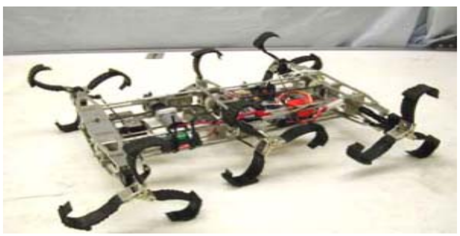


Fig.2: The Whegs robot.

Whegs [17] robots (see Fig.2) are an innovative class of walking systems that utilize a particular tri-spoke leg that try to combine the advantages of wheels in term of speed and payload and the advantages of legs in terms of climbing capabilities.

Wheels are simple to control and can develop high speed; legs allow robots to climb obstacles otherwise unreachable with a pure wheeled vehicle.

The peculiar characteristics is the design of legs: each one is realized with a tri-spoke appendage and is actuated by a single electric motor. This solution tries to fuse together the powerful capability of wheeled system in terms of speed, payload and easy maneuverability and also includes the peculiar characteristics of legged systems able to adapt over rough terrains and to climb obstacles. However, its climbing capabilities are limited as compared to the classical legs robots because it cannot change its body posture.

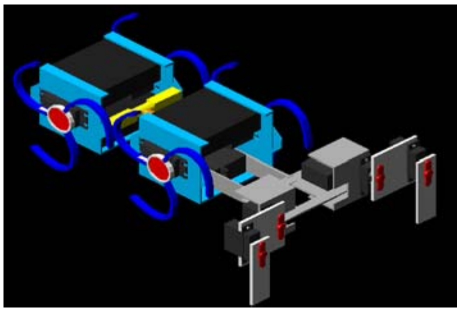


Fig.3: Mechanical model of the Trinacry_bot robot.

Fig.3 shows a 3D model of the robot, called Trinacry_bot, used for the experiments. The robot is composed of three modules. Two modules are identical and they are inspired to Whegs. A passive joint based on a spring is used to connect the two wheeled modules. This degree of freedom allows a fine adaptative of the robot posture in cluttered environment and is extremely important during obstacle climbing. The last one is constituted by two legs with 3 degrees of freedom respectively.

The standard legs module has been added to increase the climbing capabilities and to use it as manipulator. The robot can assume different configurations as shown in Fig.4.

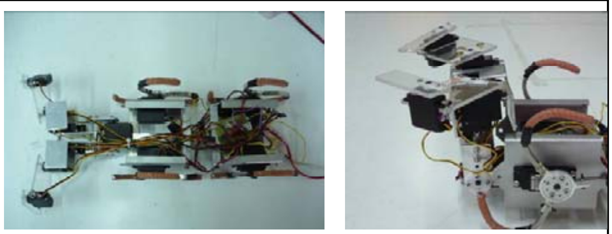


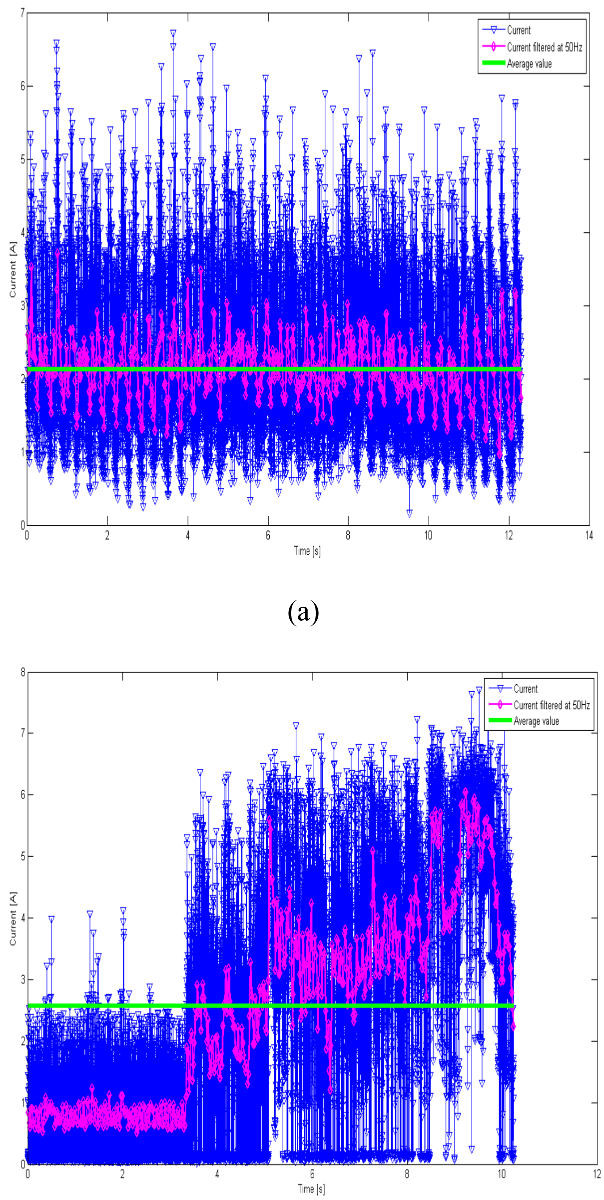
Fig.4: Different configurations of the Trinacry_bot. (a) The frontal legs are used to climb obstacles. (b) Legs are used as manipulator to take objects.

To control the robot, two boards based on ATmega64, connected using a serial bus and a graphical user interface (GUI) have been developed.
Technical information about the robot are reported in Table 3. The average power consumption on flat terrains is about 15 W. The power voltage is fixed to 6 V. In order to built an efficient autonomous power supply system, we measured an instantaneous current observed by the motor system in two different typical scenarios: movement at maximum speed on a flat terrain and obstacle climbing. The results have been obtained using a current transducer LTS 6-NP and a USB-2009 acquisition board by National Instruments.

Table 3. Trinacry_bot characteristics

Robot size (length, width)	39 cm X 8.5 cm
Robot weight	1.5 kg
Typical speed	1.5 body length /s
Spoke length	7 cm
Body flexion	± 30°
Linear Motors	HS-945MG
Legs Motors	HS-82MG
Average Power Consumption	15W

Fig.5a shows that the behavior of the current, during the movement at maximum speed in a flat terrain, changes in a fixed interval. Therefore, during an obstacle climbing, the current behavior is spiking (see Fig.5b).



(a)

(b)

Fig.5: The behaviour of the instantaneous current duirng the movement at maximum speed (a) and obstacle climbing (b). The data have been acuired at 1 kHz (blue line) and filtered at 50 Hz (violet line). The green line represents the average value.

4 Conclusion

A preliminary analysis of the feasibility of a photovoltaic system with batteries to supply a mobile robot has been presented. By analyzing both the power drawn by the robot during the movement at various speed rates and the efficiency of the most used PV cell technologies it is clear that the PV system can supply only the control, sensing and wireless transmission systems. However some qualitative evaluations on the possibility of using less power consuming motion system and at same time the presence on the market of very efficient pv cells (i.e. triple-junction) forecast the feasibility to extend the photovoltaic power to supply to whole robot. Further investigation is therefore needed in this direction.

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