PRELIMINARY ACTIVITIES TOWARDS A BATTERY CONSUME OPTIMIZATION ALGORITHM FOR PROSTHETIC HAND

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ABSTRACT

Optimization of the power consumption in Myoelectric hand prosthesis is a crucial issue that can affect the autonomy of the user and the weight of the device. This aspect seems to be barely addressed nowadays. Here we propose a high-level solution that can be implemented on a prosthetic hand, which combines a Current Sharing Algorithm and a Battery Management System with Optimal Output Current to: i) satisfy the daily requirements in terms of grasps and time, ii) enhance the battery life. This solution has been preliminarily implemented on the Mia Hand prosthesis (Prensilia SRL) showing promising results.

INTRODUCTION

In terms of consume, when used for biomedical applications, prosthetic hands can be classified as Portable Electronic Devices (PED). These are used during daily life for many consecutive hours without having the possibility to recharge the supplying power source, which usually consist of a battery pack. This aspect is often underestimated, and the result may lead to a poor design of a prosthetic hands which will require a bulky and heavy battery system. It is worth notice that "weight" represents one the most critical features for producing a successful and competitive prosthetic. In the design of robotic limbs, it is a common practice to take the weight at a minimum[1]. Due to the suspension system, and the external electronics, prosthetic devices are felt heavy by amputees even when the weight is similar to the sound limb.

The selection of the battery should also consider how the provided energy is distributed between the electronic components of the prosthetic hand. For the sake of clarity, all electronic components are going to be divided in two categories: a) **Fixed** - all components which power consumption is almost fixed during the operation (i.e. passive elements, microcontrollers, amplifier, etc.)[1]; b) **Variable** - all components which power consumption may drastically change during time (i.e. power converter, drivers, motors, etc.).

Concern must be address towards this second category in order to prevent unforeseen stress-full situations where huge amount of energy is demanded to the battery. A control strategy that does not take into account such dilemma may cause any prosthetic device to not be able to satisfy the daily operative time required by a patient or, in the worst-case scenario, may lead to battery failure. Since the described problems could ask for a re-design of the prosthetic hand, the objective of this paper is to present a high-level solution that can be implemented on any hand already available on the market. The presented solution will be divided in two parts: i) *Current Sharing Algorithm*, and ii) *Battery Management System with Optimal Output Current*.

METHOD

Case study

The case study we used is a research prosthetic hand (model Mia hand, Prensilia SRL) characterized by a transmission mechanism that implements a semi-independent actuation of the abduction/adduction of the thumb and of the flexion/extension of the index, by means of a single actuator. Thus, with only three BLDC motors the hand is capable to perform most of the grasps and gestures useful in activities of daily living [2].

Current Sharing Algorithm

Current Sharing Algorithms (CSA) are a solution adopted in systems where a common resource, in this case the current, must be shared between multiple devices. Examples of current sharing algorithms can be found in many different applications: they have become very common in power electronics([3], [4]), where multiple loads require to be supplied with the same amount of current (sometimes also referred as *Load Sharing Algorithm),* in this cases the CSA tends to make disappear any

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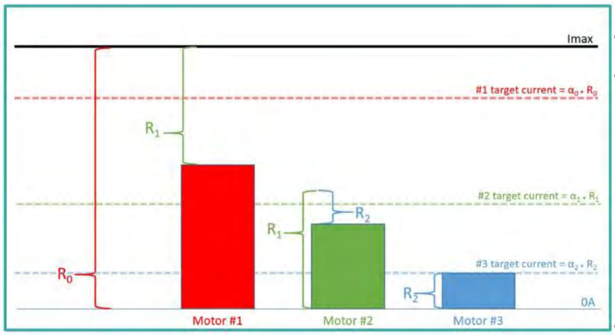
[1] The current consumed by all components changes during time since it depends on the battery voltage, but in this first category variations are so small that can be considered almost negligible.

unbalance between load currents, bringing the system to an equilibrium condition. Another application of the CSA can be found in the photo-voltaic field [Solar Array], where is used in order to provide energy in a sequential fashion to different points in a solar array, therefore optimizing the power efficiency. The algorithm presented in this paper can be seen as a generalization of the solutions presented above.

The Mia hand is a perfect example of why the solution adopted in the power systems described above cannot be exploited. In particular, in this hand the major contribute, in terms of grasping force, comes from the thumb, therefore providing the same amount of current to all fingers would not represents an efficient solution. It would be preferable to implement a sequential strategy similar to that adopted by the solar panel.



Algorithm 1: CSA - pseudo code

Result: I_{max} per motor
n = number of motors present in the hand;
$I_{residue}[0] = I_{battery,max}$;
for $(i = 1; i <= n; i++)$ **do**
    $I_{residue}[i] = I_{residue}[i-1] - I_{mot}[i]$;
    $I_{max}[i] = I_{residue}[i-1] \cdot \alpha[i]$;
end

Figure 1: Left) Motor currents shared among the motors of the Mia hand exploiting the CSA proposed. Right) Pseudo code of the CSA implemented.

The CSA developed for the Mia hand is presented in Figure 1 and can be described as follow:

1. An optimal current ($I_{battery,max}$) that the battery is able to provide is estimated. This parameter will be exploited by the *Battery Management System with Optimal Output Current* presented below;
2. Priorities are assigned to the motors according to the grasp selected by the patient/user (basically the order in which motor will move is defined);
3. The motor with the highest priority starts to move and thus starts to absorb current. The amount of current "left or available" ($I_{residue} = I_{battery,max} - I_{mot,1}$), will determine the limiting current for the second motor in order of priority[2].
4. the last item is repeated for all the remaining motors.

This process can be described as master-slave current sharing, were motor consumes current according to their priority with the commune purpose of sharing the source current without exceeding it.

Battery Management System with Optimal Output Current

The second part of the solution proposed in this paper aims to find the optimal current that the battery should provide to the CSA and that implements a *Battery Management System* (BMS). BMS are usually implemented in order to monitoring values descriptive of the pack's present operating condition. This is very useful, for example, to determine at priory the instantaneous available power that can be supplied[5]. Unfortunately, estimating the parameters needed to design a BMS could be time-consuming and expensive. For this reason, it was preferred to empirically measure the discharging characteristic of the battery adopted by the Mia hand. To this aim, a series of tests were conducted in which the hand had to perform different type of grasps while the battery voltage was recorded. The test results can be described as a series of linearized curves which shows the trend of the battery voltage: over repetitions of the same grasps and over different values of supplying current. In order to select the optimal current from a set of infinite possible choices, a constrain had to be defined. Thanks to Ian M. Bullock and his colleges [6], it was possible to evaluate the number of daily grasps performed by amputated patients. These are around 2500 grasps, divided between Cylindrical Grasps 40%, Precision 37.6% and Lateral 22.4%. In addition, from [7], [8], it was possible to determine the prosthetic daily wearing time, that is between 8 and 12 hours. This information set a target for the autonomy of the hand and thus are the target of our algorithm.

Taking into account such requirements, the optimal solution is the one satisfying the following optimization function:

[2] In order to execute this kind of algorithm, the current absorbed by each motor must be measured.

$$\textbf{objective function:} \quad \max_{I} \; \min \left(V_{end} - V_{limit}\right)$$

This is a max-min problem, where V_{end} is the estimated battery voltage level that is "left" once daily requirements have been satisfied, while V_{limit} is the minimum voltage level guaranteed by the battery. This solution can be also described as follow:

1. The number of grasps left to fulfil daily requirement are measured;
2. A combination of the remaining grasps is selected;
3. For each combination, the voltage left once daily target has been satisfied is estimated;
4. Between all possible combinations, it is selected the one that permits to consume the highest current (best performance) without turning off the battery (battery failure).

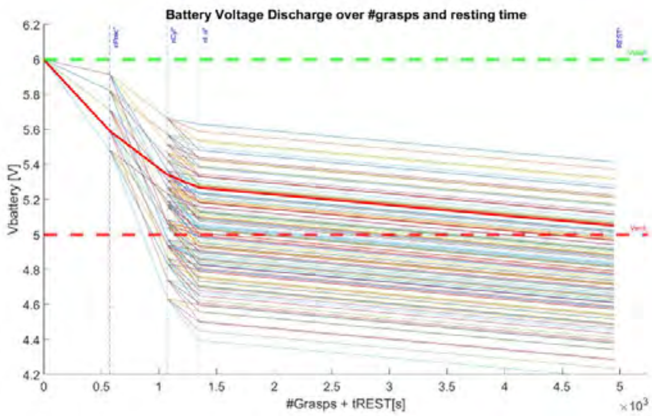


Figure 2: Example of application of the BMS with optimal output current[3].

In Figure 2 it is presented a possible scenario where a patient wants to perform a Precision grasp. The battery voltage is 6V and the minimum operative battery voltage is 5V. In this example, for each grasp, the consumed current could take one out of five different possible values. In Figure 2 it is possible to notice that not all the combinations of grasps could fulfil the daily target. The red broken line highlights the solution of the optimization problem described above. It is important to notice that grasps are ordered by the algorithm as follow: 1) The first grasp type selected is the one requested by the user; 2) The remaining grasps are order from the most consuming to the least consuming.

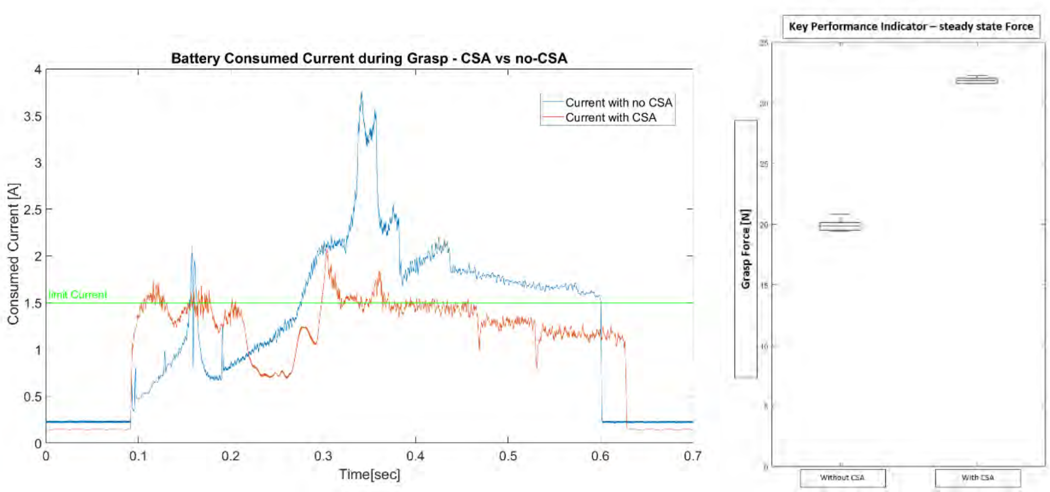


Figure 3 - Left) Battery Consumed Current - CSA vs no-CSA; Right) Grasping Force - CSA vs no-CSA

[3] The x-axis is homogeneous, first battery discharge characteristic is presented over the "left" number of grasps (#Grasps) then over the "left" resting time (tREST, period in which the hand is wore but not used).

RESULTS

The results of the discussed algorithm are shown in Figure *3*. It is possible to notice that the algorithm was able to drastically reduce the value of the maximum instantaneous power, measured in terms of maximum consumed current, required during grasp, while increasing the force exerted. The reason is that through sharing it was possible to supply the thumb motor, which is the major contributor in terms of grasping force, with an higher amount of current while preventing any degrading of the other motors performance.

CONCLUSIONS AND FUTURE WORKS

The presented work represents a preliminary study for the optimization of battery consume in the field of prosthetic hands. For the future it could be useful to: implement a model of the Mia hand battery as described in [5] and to integrate some kind of optimal control inside the CSA in order to have a more robust solution.

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