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Fuel cell powered octocopter for inspection of mobile cranes: Design, cost analysis and environmental impacts

N. Belmonte[a], S. Staulo[b], S. Fiorot[c], C. Luetto[d], P. Rizzi[a,*], M. Baricco[a]

[a] Department of Chemistry and NIS, University of Turin, Via Pietro Giuria 7, 10125 Turin, Italy
[b] Stones S.a.s., Via Risorgimento 1, 10093 Collegno, TO, Italy
[c] Environment Park S.p.A, Via Livorno 60, 10144 Turin, Italy
[d] Tecnodelta S.r.l., Via Francesco Parigi 5/h, 10034 Chivasso, TO, Italy

HIGHLIGHTS

- Design and sizing of two propulsion systems for mini UAV.
- Comparison of two propulsion systems: fuel cell and lithium-ion battery.
- Cost analysis show that power system based on hydrogen technology is more expensive.
- LCA shows low environmental impacts for both fuel cell and battery.

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ABSTRACT

In this paper, the possible development of a drone for mobile crane inspection is investigated. Since the flying time of the drones currently in commerce is too short for the designed application, proton exchange membrane fuel cells and lithium-ion batteries are considered as alternative power systems to extend the flying time. Both systems are analyzed from an economical point of view and a life cycle assessment is performed to identify the main contributors to the environmental impact. From a commercial point of view, the lightweight fuel cell, being a niche product, results more expensive with respect to the Li-ion battery. On the other hand, the life cycle assessment results show a lower burdens of both technologies with respect to other components of the two systems, as carbon fiber. The source of the hydrogen and the electricity mix play a critical role as well.

1. Introduction

Unmanned Air Vehicles (UAVs) have traditionally been used in military operations for a number of years [1]. Recently, UAVs have generated increasing interests due to their potential application in civilian domains [2], such us glaciology [3], agriculture [4,5], monitoring of erosion phenomena [6], geothermal environments [7], surveillance of open cut mining sites [8] and archaeological areas [9].

In recent years, electric propulsion systems become popular among small or mini UAVs for several reasons, i.e. quiet operation, easy and safe handling and storage, precise power management and control [10]. The main drawback of this solution, however, is the limited flying range of the device. A lot of efforts have been dedicated to the estimation and optimization of the flying range in electrical UAVs [11,12]. As pointed out by Simic et al. [13], increasing the battery size is not a viable solution, since the weight becomes a limiting factor. Rajendran et al. [14] suggested a solar-powered UAV for areas having considerably high irradiation. In this case the device could fly ideally all the day, powered directly with the electrical current produced by the photovoltaic panels and the excess of energy can be used to charge a buffer battery. Chang et al. [15] obtained an increase of the flying range up to 17.6% dividing the battery in small modules and introducing the possibility of dumping some exhausted modules during the flight, reducing the weight of the drone. This solution, however, is not generally applicable. In a study by Simic et al. [13] the possibility of charging the UAV on the job using wireless energy transfer (WET) is suggested. In this case, in fact, the drone might be used for inspection of power transmission lines and towers. This possibility was not tested yet on a power line, but the authors performed several lab experiments on wireless energy transfer, obtaining encouraging results. Also this solution, which still needs some further developments, is not widely applicable.

Another option to increase the flying range of a UAV is the use of a

* Corresponding author.
E-mail address: paola.rizzi@unito.it (P. Rizzi).

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fuel cell to generate electricity. In this case, once the power is defined according to the needed features of the UAV, the only limit of the flying range is given by the amount of fuel that the device can carry. This possibility has been explored in many works: Renau et al. [16] studied the integration of a HT-PEM (high temperature PEM fuel cell) on a UAV for high altitude (about 10 km) missions, Brandley et al. [17] integrated a conventional PEM fuel cell on an unmanned aircraft for lower altitude missions, with respect to the previous case. PEM fuel cell stacks seem to be the most appropriate solution for UAVs, due to accomplished high operational parameters, reliability and commercial availability [18–20]. Dudek et al. [10] tested a hybrid PEM fuel cell and Li-ion battery system. In a study by Kim et al. [2], a PEM fuel cell is coupled to a metal hydride storage tank for application on UAVs.

A comparison of performances of battery and fuel cell systems has been reported, for both mobile [21] and stationary [22] applications. Battery systems are usually more efficient than those based on fuel cells, but require higher recharging times. Fuel cells are usually less flexible in operations, as evidenced by the need of suitable start-up procedures before reaching the best performances. Fuel cells have intrinsically higher running times, only limited by the fuel feeding. Up to date, no direct comparison between battery and fuel cell systems for UAV applications are available.

In this paper, a feasibility study is carried out to evaluate the application of a PEM fuel cell to increase the flying range for a UAV. Unlike the previous reports, however, the PEM system is considered to be set up into an octocopter instead of a monoplane. In this study, not only the planning of the system is considered, but also a cost analysis has been performed. In addition, a Life Cycle Assessment (LCA) analysis is carried out to evaluate the most important contributors to the environmental impact relative to the production of the drone and to its use. Together with the fuel cell-powered UAV, a similar battery powered device is considered, representing in fact the most used and commercially widespread technology. A comparison between the two systems is made, considering technical aspects, costs and environmental impacts.

2. Designed application

The application of the drone considered in this study is the periodical inspection of lifting equipment and cranes. These inspections have to be performed, in Italy, according to ISO 4301-2:2009 and UNI EN 13000 Mobile cranes Normative that individuate some critical components, which have to be periodically inspected by qualified technicians. To this purpose, these components are currently disassembled and put on the ground, but this procedure is expensive and time consuming. In order to avoid this step, video inspection performed by drones can be a valid alternative. This can be done by implementing a First-Person-View (FPV) system on the drone. FPV refers to the management of a remote control aircraft or vehicle while using an onboard camera that sends real-time video to either a video monitor or video goggles.

According to the application, the main features required for the drone are a high stability, a flying time of at least 120 min and a suitable image acquisition system. These needs address the choice towards a mini hexa or octocopter, for their higher stability with respect to quadcopters. Hexa and octocopters are more powerful with respect to quadcopters, but also heavier. These considerations, together with the need of a long flying time, require a powerful battery or, in the case of the fuel cell, not less than 1 kW power output. In both cases, the weight of the battery/fuel cell with these requirements is around 1 kg. As image acquisition system concerned, a high resolution video camera is needed, with support and transmitter onboard, with a video receiver and a screen on the ground. One of the main critical aspects of the camera is its weight, which ranges from 0.3 kg of a GoPro-type camera up to 1.5 kg for a full frame reflex camera. Further evaluations on the type of drone, as well as the power supply, will be discussed in Section 4.

Table 1
Specifications of the UAV used for the tests.

UAV type	Hexacopter
Nominal power per engine	380 W
Maximum power reached during the tests	360 W
Battery weight	1050 g
Empty weight	2440 g
Extra load used for the tests	1000 g

It must be pointed out that the main purpose of this study, rather than the construction of the drone, is the evaluation of the environmental burdens associated with the manufacturing and use of a hydrogen-powered PEM fuel cell drone compared with those associated to a similar battery-powered one. Lithium-ion batteries in fact are currently the most used for propulsion of mini UAVs.

3. Tests

In order to verify the feasibility of the integration of a PEM fuel cell on a UAV to increase the flight time, a preliminary study has been carried out on the electricity consumption of UAV's engines in different flight conditions. This allowed identifying the load variations the fuel cell undergoes. Once load variations have been identified, a bench test has been performed on the fuel cell to verify its response to the different flight conditions.

3.1. Flight tests

The flight tests were carried out with a battery-powered hexacopter, having the specifications reported in Table 1.

It is worth noting that the main purpose of the flight tests was to identify the energy requirements of the engines in different flight conditions, and not to size the system.

The variation of the electrical current absorbed by the engines is reported in Fig. 1 as a function of the time for a flight in "dynamic" conditions (green[1] curve) and in "normal" mode (blue line). The "dynamic" flight mode consists of sudden accelerations and quick direction changes, successions of landings and take offs, which correspond to the peaks in current intensity. It can be noticed that the absorbed electrical current is close to 20 A, but it may vary significantly in few milliseconds. The "normal" flight mode, on the other hand, consisted of a flight at constant speed after takeoff. In this case, the absorbed electrical current is almost constant at 20 A during the whole flight, except for the small changes of 5–10 A that can be associated to repositioning of the UAV.

The "normal" flight mode is similar to the operating conditions of the drone for the chosen application: image acquisition of structural parts of high cranes in fact implies reaching a position, which is not necessarily to be performed at the maximum speed, and keeping it for several minutes for image acquisition.

3.2. Fuel cell bench tests

Once performed the flight tests to register the load curves, a bench test was performed on a PEM fuel cell in order to verify not only the possibility of using the latter for drone power supply, but also to evaluate if electric transient dynamics are compatible with the requirements of the engines. The system is composed by a microprocessor-based controller managing contemporarily load flows between the fuel cell, the battery and the engines. There is a further part dedicated to power supply for the auxiliary components (powered by

[1] For interpretation of color in 'Fig. 1', the reader is referred to the web version of this article.