CONCEPTUAL DESIGN AND FEASIBILITY STUDY OF ACROBAT, AN AUTONOMOUS CLIMBING ROBOT FOR AUTOMATIC TRIMMING OF PALM LEAVES

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ABSTRACT

Despite the constant technological innovations, the pruning of palm trees is still carried out manually by skilled operators, with the aid of climbing devices and cutting tools. The present work stems from the need to replace humans with robots in the activities of climbing and pruning of palm trees, so as to eliminate the severe danger related to the height and the difficulty of cutting operations. Human workers are indeed exposed to risk of injury, due to possible accidental falls, cutting, skin punctures, dust inhalation, flying splinters.
Pruning of palm trees has a frequency variable from 2 to 4 years. For a single pruning carried out by one operator, the cost is approximately 500 Euros. Therefore, the use of a robot, other than risks, allows decreasing costs as well.
In the paper, the conceptual design of a pruning robot is presented; it basically consists of a climbing module on which it is mounted a cutting module. The cutter is capable of a continuous rotation (i.e. exceeding 360°), that allows to perform a complete cut of the dead leaves located in the lower part of the palm crown. Special care has been devoted to the intrinsic safety aspects, fast installation and ease-of-use of the robot, along with a low overall cost for both off-the-shelves components and manufacturing of custom-made structural parts.

KEYWORDS: Climbing Robot, Pruning Robot, Safe Pruning, Palm Tree Pruning.

1. INTRODUCTION

The passage from man as a human labor force to man as a machine operating controller is one of the main features of the present age. This work aims at stretching the key guides and rules of the ACROBAT project: palm trees have become quite familiar in the European landscape and need a regular trimming to grant public safety. Safety plays a key role and two aspects must be tackled: the safety of the palm and the safety during the pruning operations. Until now, this job has been carried out manually by specialized operators with the consequent risks involved.

As a general rule, to assess the state of the palm, a visual non-destructive examination is done by highly qualified personnel. In fact, not necessarily a dry leaf presents a real risk of detachment and, therefore, of potential fall; on the other hand, it is possible that, as a result of an unexpected event such as strong wind, one or more leaves are damaged despite being still green, thus forcing their removal.

In parallel, the safety of the pruner is of outstanding importance: in fact, there are many risks associated with the activity of pruning at high altitude. The operations are performed on lifting platforms where possible, otherwise climbing directly on the trunk, using a sling and a device called "*bicycle*". In addition to the height, possible risks are related to the use of cutting tools and to the airborne removed material.

2. THE “ACROBAT” APPROACH

In virtue of these considerations, ACROBAT, a climbing and cutting robot for palms, was conceived in order to subtract the man from a high risk activity, automate the pruning process and lowering its unit costs.

Due to its world-wide spread, it was decided to focus on the palm named “*Phoenix Canariensis*”, which is characterized by a trunk diameter of 800 mm on average. The robot, therefore, is designed to adapt to diameters in the range of 600÷1000 mm. The robot has a modular architecture: it consists of a climbing module and a cutting module, that can be mounted at the time of pruning. Modularity allows to easily replace the cutting module with other specialized modules (e.g. for monitoring tasks).

In order to choose the best possible architecture, during the conceptual design phase, the following tools have been used:

- Objectives Tree to determine the quality ofthe product attributes;
- Morphological Matrix to assess all the technological solutions suitable for achieving the ultimate goal;
- Evaluation Table to determine the best design concept.

As for the climbing module, the optimal configuration results in the following features: *a)* continuous motion of ascension achieved via a series of actuated wheels; *b)* transmission of the anchoring forces through a system of springs. As for the cutting module, the optimal design results in the following features: *a)* an alternating rotary motion system; *b)* a combined circular saw which, simultaneously, trims the leaves while performing a finishing action thanks to a special side profile of the cutter.

2.1. CLIMBING MODULE

The climbing module consists of a frame which can be split in two sub-frames whenever it has

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to be removed from the palm trunk. With reference to Fig. 1 (left), arc shaped clamps, C, firmly fix the robot during the cutting phase, while supports, L, host the rail of the cutting module. Three wheels are actuated for the rise/descent motion by moto-reducers with embedded, normally-closed, safety electro-brakes. Wheels are pushed against the trunk by leaf springs, E, working above their buckling compressive load, hence granting a quasi-constant force during their 50 mm stroke, Fig 1 (right). A nut-and-screw system allows for the initial setting (according to the trunk diameter) of the position of the elastic group, E, linked to the trolley, T, which can slide on the channel, H, Fig 1 (right).

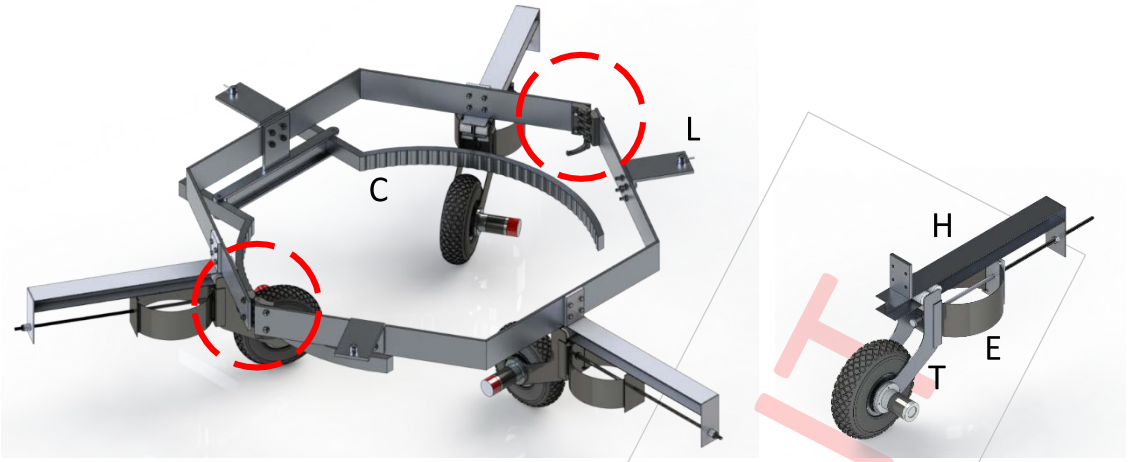
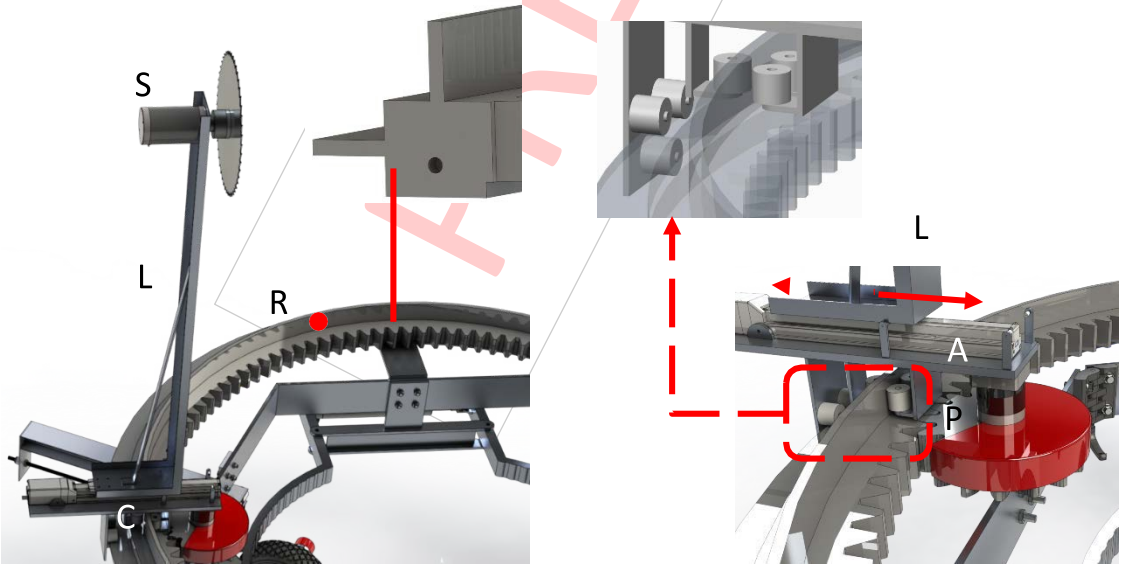


Figure 1. Left: View of the climbing module. Dashed circles show the connections for mounting/unmounting the robot around the palm trunk. Right: the motorised wheel is mounted on a trolley T pressed against the palm trunk by a couple of leaf springs E.

2.2. CUTTING MODULE

With reference to Fig. 2, the cutting module is made of: *a)* a crown rail, R, (composed of two units joined together with a female-male mating) with inner toothing; *b)* a cart, C, which runs on two ribs (a radial one and an axial one) by means of six idle wheels (to prevent any motion except the circumferential one), and driven by the pinion P. The cart C hosts a compact linear actuator, A, which carries the frame, L (and can move it radially back and forth). The same actuator holds



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in place the electric saw, S, when needed.

Figure 2. Left: the cart C running onto the rail allows a 360° cutting of the palm leaves. Right: the actuator A adjusts the distance of the cutting blade according the palm size.

3. CONCLUSION

ACROBAT, Fig. 3, is a solution potentially capable of performing the pruning of palm trees in safety, with higher speeds, lower costs and constancy of the results compared to manual operations.

The advantage of having the climbing system independent from the cutting one, allows to create new modules with different functionalities. For example, it would be of great interest an "inspection" module capable of analyzing the state of health of the trees and check for the presence of red punch: this insect is a real threat to the survival of the palms.

Another hypothesis is its use on other types of trees, for example for the pruning of the lower branches.

Figure 3. Overall 3D view of ACROBAT: resting position (left) and performing a pruning operation on a palm trunk (right).

4. RESULTS OF THE INVESTIGATION LINE

This robot is the last of a serie of mobile robots which were conceived by the authors that are part of the Mechanical Computer Aided Engineering Laboratory (MCAELab) of the University of Genova, Italy.

The most significant ones are listed below:

- A physical prototype of a 3 tons climbing robot for landslides prevention: “A Robotized Drilling System for Rocky Wall Consolidation”, *22nd International Symposium on Automation and Robotics in Construction, ISARC 2005*;
- A mobile robot conceived for security/sruveillance tasks: “Mobile robots for airports surveillance: a modular solution”, *Proceedings of ESDA2006 8th Biennial ASME Conference on Engineering Systems Design and Analysis, 2006*;
- A service robot for domestic use: “Gecko, a climbing robot for

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walls cleaning", *Proceedings of ASER 2003, 1st International Workshop on Advances in Service Robotics, 2003*;

- A physical prototype of a small mobile robot for inspection tasks: "Epi.q-TG: mobile robot for surveillance", *Industrial Robot: an International Journal, Vol. 38(3)*.

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