Zebro Light: Lightweight Mobile Hexapod Robot

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Abstract

In this paper, we present a mechanical, electrical and software design for a lightweight, mobile exploration robot that employs the half-circle leg morphology. Due to its small size and weight, the robot is capable of exploring areas where existing walking robots cannot go. The robot's structure has been designed to be lightweight, without compromising its robustness. The electronics and software are designed to make each leg follow specified reference trajectories, by actively controlling motor position using feedback from rotary encoders. A prototype of the design has been constructed and tested, demonstrating a stable walking behavior. Adaptability of the mechanical design and high performance of the on-board computer allow this design to be used as a versatile platform for research on walking exploration robots.

I. Introduction

While robots are still mainly used for industrial applications, they become increasingly popular for civil and defense purposes. Robots may be designed to assist humans in households, or to explore areas with uneven and rough terrain. Such exploration robots can be used to search for survivors in areas affected by natural disasters, while carrying payloads such as medicine and food, or explore areas where no humans have gone before.

Examples of these robots are the RHex [1] and the Zebro [2], employing a half-circle leg morphology especially suited for rough terrain [3]. While these robots are robust and relatively fast, they are limited in their ability to navigate in small spaces due to their size and weight.

It is therefore desired to develop a robot that maintains the robustness and versatility while reducing the dimensions and weight of the robot significantly. This leads to the objective to develop a mechanical, electrical and software design for a small, lightweight, rough terrain robot with legs based on the half-circle morphology.

In the near future, this robot will be used for further research on walking robots. It should therefore be easy to modify the design and it should be possible to expand it with additional hardware such as communication devices for research on robot swarms.

II. Design Method and Criteria

The Zebro Light has been developed with several requirements and constraints in mind. Constraints in costs (€3000), weight (3.5 kg: half of original Zebro) and dimensions (300x200x60 mm: roughly half top surface area of original Zebro) are amongst the most important.

The requirements include the ability to move on rough terrain, both in normal mode and in inverted mode (upside down), and the ability to carry payloads of its own weight. To meet these requirements, minimum values have been imposed for the capabilities of the motors: 3.5 Nm for torque and 350 rpm for speed (no load).

To compare the robot's walking efficiency with the original Zebro, the 'Cost Of Transport' (COT) will be measured. This dimensionless quantity [1] is given by:

$$\mathrm{COT} = \frac{P}{mgv} \tag{1}$$

in which P is the power consumption, v the corresponding speed and mg the weight of the robot. The COT is required to be similar to that of the original Zebro.

The following sections will discuss the design choices that have been made by means of multi criteria analyses (see design report) for the mechanical, electrical and software design in order to meet the requirements.

III. Mechanical Design

The mechanical design defines the overall morphology of the robot, indicating the design of the robot's structural frame to which the actuators with legs are mounted.

In order to reduce weight, polycarbonate plates have been chosen for the structure of the frame. This lightweight plastic has a very high impact strength, which is favorable in rough terrain operation. Although they are lightweight, these plates have a low stiffness. To introduce stiffness in the frame we designed a 'sandwich' structure, with two polycarbonate plates enclosing six aluminum boxes, in which the motors are mounted (see Figure 1). Because of the introduced distance between the plates, the second moment of area of the frame – and therefore the stiffness – increases significantly. Finite element method simulations show that a thickness of 2 mm is sufficient to withstand the maximum load that the motors can exert on the frame. Overall, this structural design results in a robust, lightweight frame construction.

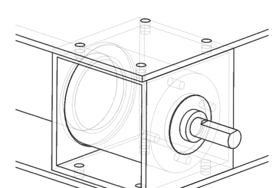

Figure 1: Motor unit

IV. Electrical Design

The electronics design encompasses all components required to drive the motors in a pattern that results in a stable gait. Figure 2 shows the main components along with the most critical power and data flows. The controller, printed circuit board (PCB), motor driver and motor unit form a closed loop with a time reference trajectory [2] as input and leg position as output.

We have designed a custom PCB to interface between the controller and the incremental rotary encoders, in order to reduce the load on the controller. The other components have been selected for high computing power and capability to supply large currents, while keeping weight and dimensions low.

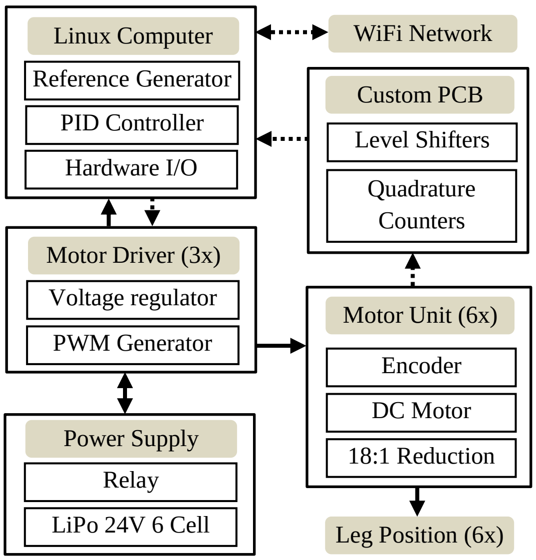

Figure 2: Electronics design with data signals (dashed) and power signals (solid).

V. Software Design

The software turns the electromechanical system into a functional robot by retrieving sensor data and controlling the motors accordingly. The software design allows a user to control the robot with basic functions like walking or turning without knowing about the hardware controls involved in these operations.

We have developed a C++ application that can read sensors and control motors up to 480 Hz, using only a fraction of the controller's total processing power. A leg controller class has been designed that abstracts each leg module as one object with properties such as leg position, leg gait type, and PID constants, as well as functions to make the leg move according to position reference signals. This allows the same code to be used for more complex walking behaviors.

VI. Results

An actual prototype of the Zebro Light has been built and tested to verify whether the design meets the requirements and how it performs in comparison with the Zebro (Figure 3). The prototype demonstrates stable walking behavior. Table 1 presents its specifications.

The average power consumption in equation (1) is measured as the current (measured using a data logging scope) multiplied by the voltage (across the battery terminals) while walking on a linoleum floor. The maximum speed has been measured on a grass surface over a distance of 5 meter. Table 2 shows the experimental results.

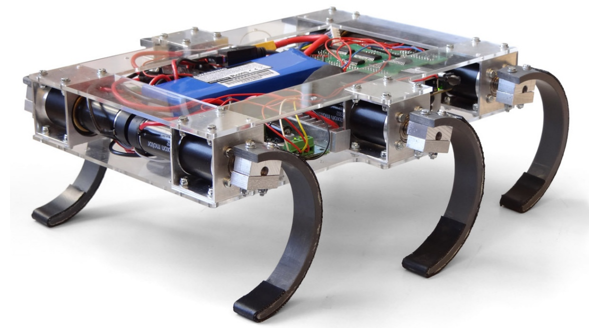

Figure 3: Zebro Light prototype.

Table 1: List of specifications.

Specifications	Required	Prototype
Weight	3.5 kg	3.2 kg
Costs	€3000	€2500
Dimensions	300x200x60	294x187x44
Stall torque	3.5 Nm	5.85 Nm
No load speed	350 rpm	605 rpm
Sampling frequency	200 Hz	200 Hz

Table 2: List of experimental results.

Experimental Results	
Maximum speed on grass	0.40 ± 0.03 m/s
Permissible payload	5.0 kg
COT on linoleum floor	7.5 ± 0.3

VII. Conclusion and Discussion

The tables show that the first prototype meets the constraints imposed on the design, reducing the weight by 59 % and the top surface area by 51 % compared to the original Zebro. The stable walking behavior shows that the electrical and software design perform as expected, even with a payload up to 5 kg. The COT value is close to that of the Zebro (its average COT on linoleum is 7.8), indicating that our prototype has a similar efficiency.

The on-board computer is capable of controlling the motion of each leg at the required control frequency, using only a small fraction of its total processing power. Combined with the adaptability of the mechanical design, this demonstrates the versatility of the Zebro Light as a platform for further research on walking robots.

References

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