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# Energy Efficiency of Robot Locomotion Increases Proportional to Weight

[Extended Abstract]

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## ABSTRACT

The task of producing steady, stable and energy efficient locomotion in legged robots with the ability to walk in unknown terrain have for many years been a big challenge in robotics. This work is focusing on how different robots build from the modular robotic system, LocoKit by Larsen et. la [3], performs compared to animals, and also on the similarities between robots an animals. This work shows, that there in robots exist the same connection between cost of transport and the weight of the robots as is true for animals.

## Keywords

LocoKit, Quadruped, Robot, Modular Robot

## 1. INTRODUCTION

Locomotion, and the ability to move is perhaps the most important ability that creatures on earth have. Animals are constantly in movement to find foot, or to protect themselves against predators. In the world of robots, moving around on legs is however a difficult problem, which a lot of scientists have been working on for decades. The problem that still is facing us today is, how to make walking robots able to handle unknown terrain in an robust and lithe way, which would make it easier to embed moving robots into our daily life as service robots.

In the Locomorph project, which is a EU project shared between 6 partners[1], we will create novel walking robots with increased efficiency and robustness, in order to enlarge the area into which robots can be applied in our daily life. This will be done through a multidisciplinary approach by combining biology, bio-mechanics, robots, and embodied artificial intelligence.

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One part of the project is to create heterogeneous key modules from which, a variety of legged robots can be build. In the end of the project, these modules will be used to develop a preliminary prototype of an educational robotic toolkit, which will be used in a summer school.

Now, the first working prototype set of heterogeneous modules have been created, which are able to perform legged locomotion in various configurations. This novel system is called LocoKit. This poster will show the latest results in walking with LocoKit, and show how the robots build with LocoKit performs compared to each other, and to animals.

We have tested the robots primarily on flat surfaces, measuring the power consumption, speed, and distance travelled, to make it possible to calculate cost of transport (COT) for all of the robots. The COT is energy divided by mass times distance travelled ($J/m^{-1}kg^{-1}$), and it tells how efficient an animal or robot is to move. Having a COT value for the robots, also makes it easier to compare them to animals, because the same value is used in biology. Our tests shows, that the COT of LocoKit robots, have the same relation to their weight, as the COT of animals have to their weight. The tests does however also show, that the robots are far from being as power efficient as animals. The COT of our robots is roughly a factor 6-10 above animals of similar size.

## 2. WALKING WITH DIFFERENT ROBOTS

### 2.1 The LocoKit System

In order to fulfil the requirement of producing a prototype building kit, a novel modular robot with an more extreme form of heterogeneity than previously seen in modular robots [4][5] will be designed. The reason for doing this, is to optimise the system more towards legged locomotion, than previous have been done in modular robotics [2].

From nature it is known, that the body of vertebrates normally can be divided into three categories, namely skeleton, skin/muscles, and organs/brain. The same principle have been thought into the design of LocoKit. When building a robot using LocoKit, one will start with the skeleton of the robot. With the skeleton in place, the actuation will be mounted onto the skeleton in the right places. Having the actuation and the skeleton separated, makes it possible to have the motors placed into the most optimal positions on the robot. This way, it is possible to take the weight distribution into account in the assembling process.

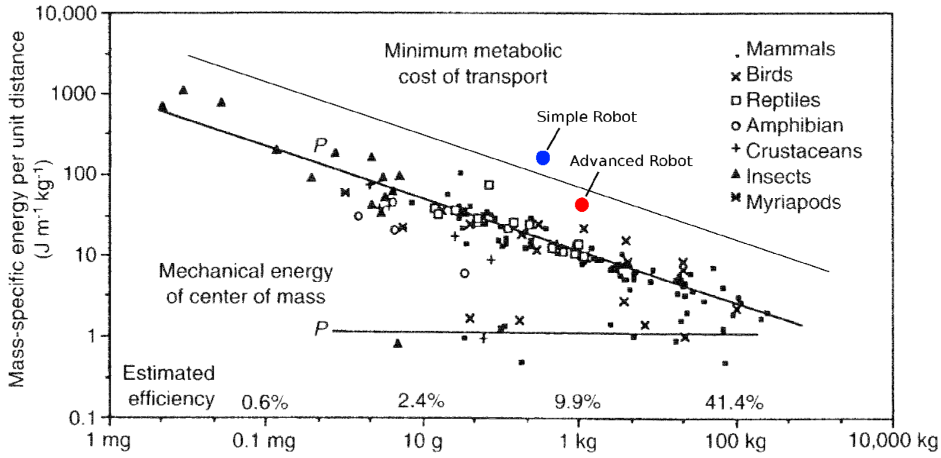


**Figure 1: The graph shows the cost of transport plotted against the weight of various animals, together with the COT values for the two robots -** ***(red) advanced robot, (blue) simple robot.*** **The horizontal line marked "P" tells the mechanical cost of transport of some animals, and not used in this work. Full et. al [1]**

When the actuation and skeleton is in place, the electronics/batteries/wiring can be attached to the robot.

## 2.2 Experimental setup

In the following tests, two robots of different size and complexity where build. Both robots are quadrupedal, and both do they have a fixed body onto which the legs are mounted. In order to save power, all motors are doing continues rotations on both robots. The legs on the advanced robot is based on a linkage-bar system, where two actuators per leg are rotating constantly with some phase between them, which makes it possible to adjust the trajectory of the legs from the controller. On the simple robot, the leg are sliding in a rotating joint, which gives the leg an elliptic trajectory which is fixed by the skeleton. Only one motor is used pr. leg on the simple robot.

To test the walking capabilities of the robots, two different setups have been used. One was a parcour, where the terrain can be adjusted from a flat surface into a surface with slopes. The other setup was a treadmill. On both setups a flat terrain have mostly been used, because the robots capabilities of walking in unknown terrain, is yet to be improved. All data in the following is based on flat terrain.

## 2.3 Results

The experiments show, that the performance of the robots compared to animals of the same size is roughly 6-10 times less efficient, see figure 1. The experiments also show, that the two robots actually have the same inverse coupling between the COT and the weight as for animals of the same size. In all of the experiments on which these data are based, both robots was walking in a diagonal sequence - diagonal coupled gait, also known as a "imperfect trot".

# 3. CONCLUSIONS

The results of the COT values on the two robots show, that they are 6-10 times less efficient when compared to animals of equal size. It will naturally have high priority to improve the COT for LocoKit robots in the future, but for now it is not surprising that the performance of the system is not as good as in nature, since the system is still in its development phase. What is more interestingly is, that the COT value of the robots are having almost the same relation to the weight as seen in nature. In the future, further tests will be performed, where the weight of the simple robot will be increased to the same as the advanced robot, in order to see if the two different morphologies will perform equal if they have equal mass.

# 4. ACKNOWLEDGMENTS

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