K-Rock, a Bio-robot Outside the Lab, Back In Nature

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1 Introduction

Studying biology to inform (or inspire, as some authors call it) the design of robots and other engineered machines, certainly offers benefits in two mainstream directions: (i) One can **abstract** the morphology and function of organisms in nature, in order to incorporate design principles into the creation or improvement of engineered materials, devices and processes. Results of these studies, are somewhat indistinguishable from their biological sources. Particularly in robotics, there are abundant examples of such studies, e.g. the gecko-inspired adhesion technology [1], or the design, implementation and control of muscle-like variable stiffness actuators [2], among others. (ii) On the other hand, one can **replicate** pieces of biological morphology and study its function by designing robots, very often by using data from a strong empirical base. These Bio-Robots are then used as tools to understand the specific biological principles that drove their creation in the first place. Additionally, as the morphology is crucial in these studies, the engineered results share many characteristics of the form of its biological sources. Undoubtedly, in the study of animal locomotion (and multi-modal locomotion), bio-robots are taking place as important tools, with applications ranging from study of neural locomotion control [3], body dynamics [4], and gait performance [5] to even terrain interaction [6].

As reported in literature (see [7] for a review), biology is constantly abstracted and/or replicated in robot designs either for improving engineering or studying biology. However, reports of **confrontation of these bio-robots with the natural environment of their living counterparts** are hardly available. Roboticists constantly claim that their bio-robots can potentially be used for a number of application domains. These domains –particularly in the case of locomotion studies– include largely the Search and Rescue, and Disaster Response missions. However, except for a few cases reported to date [8, 9], arguably no bio-robot has sufficient capabilities to tackle realistic scenarios and their use and testing remain inside a controlled space in a laboratory.

Notably, the environment inhabited by an organism, should offer an adequate scenario to test the capabilities of the bio-robot, created respectively by/for studying such organism. Moreover, in order to extend satisfactorily the applications of their creations (i.e. disaster response), roboticists require to learn about the challenges that the field poses beforehand. Consequently, the holistic context of testing in a natural scenario is in general, beneficial for the design of a fair reproduction of morphology and function, in contrast with nature-isolated versions of bio-robots.

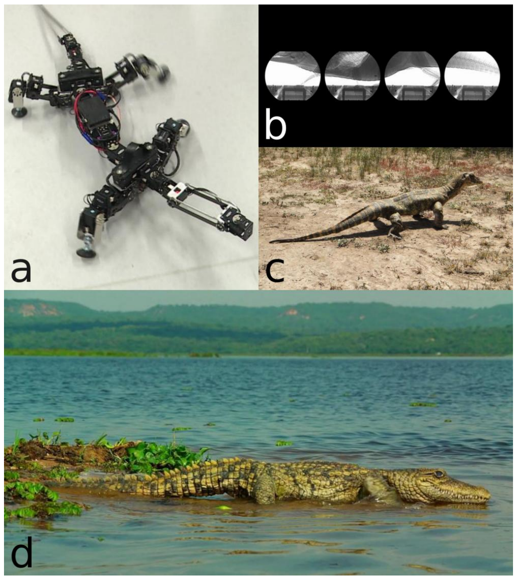

Figure 1: K-Rock: a.) Fully functional robotic skeleton, b.) X-ray recordings of a caiman, c.) Field test in lizard mode, and d.) Land to water transition in crocodile mode.

On this regard, our laboratory works in two different lines of research, namely the study of animal locomotion (i.e. salamanders), and the transfer of this knowledge to the design of robots and locomotion controllers for search and rescue and disaster response. In November 2015, BBC's producers (John Downer Productions JDP) approached us. They wanted to leverage our expertise designing sprawling posture robots (i.e. Pleurobot [3]), to create two animal-like robots to be used in filming wildlife documentaries in Africa. The chosen animals were a young Nile crocodile (*Crocodylus niloticus*) and an adult monitor lizard (*Varanus niloticus*), both sharing the same snout-to-vent length SVL= 90*cm*, (1.2*m* total length). This opportunity came in a moment where a novel design of an amphibian sturdy sprawling posture robot, was planned. We took the challenge of designing K-Rock (Fig.1a), a robot aimed to cope with the expectations of the NCCR-Robotics Rescue Challenge [10], in the modalities of legged multi-modal locomotion and field test actions. Simultaneously, this robotic served as platform to fulfill the requirements of BBC.

This was a rare chance to glue it all together: the bio-informed design of a novel amphibian sprawling posture bio-robot, the field-ready improvements of previous robot versions, and particularly, the unique occasion to confront such a robot in the natural environment. To the best of our knowledge, we believe this is the first time that a bio-informed robot is actually designed to tackle the same environment as that of its biological source of information.

2 Design Methodology and Gait Control

In order to design K-Rock, the morphologies of crocodiles and monitor lizards were studied using photographs of skeletons of the same taxa (Cantonal Museum of Zoology, Palais de Rumine, Lausanne, Switzerland). A young crocodile and an adult lizard shared roughly the same length as the final robot version, thus no scaling was required. Additionally, the design of these two different animal morphologies was simplified in a single robotic skeleton with slightly differences in the head/neck and tail for the two modes. Body segmentation was determined by choosing relevant joints to be reconstructed. However, the maximum number of joints in the robot was limited to $N = 24$, due to the actuator weight and the relevance of the joint in the overall kinematics. The robot's joint count correspond to: head/neck (3), spine (2), legs (4 each) and a tail (3). In order to reduce weight and increase robustness, carbon fiber and aluminum alloys were used in the robot's structure. The total weight ($5.3kg$ without skin) was significantly reduced from previous sprawling posture robots versions in our laboratory by roughly 50% [3]. A long range communication system using XBee-PRO® 868 RF modules was implemented. In addition, a waterproof enclosure that comes along with the latex skin (property of JDP) was added to the robot to protect the actuators and battery in aquatic operation during filming.

To control the robot, motion in crocodiles and lizards was studied. From video footage of walking animals and, in the case of the crocodile, x-ray recordings of a caiman (Fig.1b, courtesy of John Nyakatura, Humboldt University of Berlin), leg and spine kinematics were reconstructed. Then, by using a similar methodology as that in [3], the locomotion controllers were tuned to achieve sustained sprawling locomotion and steering control [11].

3 Results

K-Rock was extensively tested in Uganda (Murchison Falls) for two weeks during the filming of the documentary *Spy in the Wild* in June 2016 [12]. The field testing conditions were broad, namely high temperatures (38°C, roughly 75°C inside the latex skin), natural uneven terrain, muddy river banks and of course the Nile river. The modular, *man-packable* robot design incorporates field-ready capabilities like: easy deployment, long range communication systems and a waterproof suit used for the amphibious operation. Two bio-robot were implemented with K-Rock. A monitor lizard version (Fig.1c) and a crocodile version (Fig.1d). The gait controller was tuned directly on the field according to the natural terrain characteristics encountered, and by respecting kinematic data extracted from the animals. Extensive footage of the robot in action is featured in Chapters 3 (Friendship) and 5 (Meet the Spies) of the documentary [12].

4 Discussion

Many aspects never foreseen in preliminary laboratory tests were encountered under the field tests of K-Rock in Africa. Temperature overheating and torque overloading were the main reasons of robot failure. Motion hindrances and overweight due to the tight latex skin also prevent the gaits to reach fully realism. The re-creation and quantification of these aspects in isolated tests in laboratory conditions allowed us to understand better these failures and improve the overall robustness of the robot design in future versions. Through this work, we were able to demonstrate the full loop of bio-robotics. It started by drawing geometric and kinematic data from real animals to design a bio-robot, followed by using this robot for relevant fields such as entertainment (BBC example), locomotion, and improvement in robot designs for disaster response. It also propose new avenues of research like exposing these robots in natural environments to study animal-robot interaction. In other words, taking the bio-robots outside the lab, back in nature.

References

[1] Cutkosky, Mark R. Climbing with adhesion: from bioinspiration to biounderstanding. Interface Focus 2015 5 20150015; DOI: 10.1098/rsfs.2015.0015. Published 15 May 2015.

[2] B. Vanderborght, et.al., Variable impedance actuators: A review, Robotics and Autonomous Systems, Volume 61, Issue 12, December 2013, Pages 1601-1614.

[3] Karakasiliotis, K., Thandiackal, R., Melo, K., Horvat, T., Mahabadi, N. K., Tsitkov, S., and Ijspeert, A. J. (2016). From cineradiography to biorobots: an approach for designing robots to emulate and study animal locomotion. Journal of The Royal Society Interface, 13(119), 20151089.

[4] Thomas Libby, Talia Y. Moore, Evan Chang-Siu, Deborah Li, Daniel J. Cohen, Ardian Jusufi and Robert J. Full. Tail-assisted pitch control in lizards, robots and dinosaurs. Nature 481, 181–184, 12 January 2012.

[5] Ananthanarayanan, A., M. Azadi, and S. Kim, "Towards a bio-inspired leg design for high-speed running", Bioinspiration and Biomimetics, vol. 7, issue 4, 2012.

[6] Hamidreza Marvi, Chaohui Gong, Nick Gravish, Henry Astley, Matthew Travers, Ross L. Hatton, Joseph R. Mendelson III, Howie Choset, David L. Hu, Daniel I. Goldman. Sidewinding with minimal slip: Snake and robot ascent of sandy slopes. Science, 10 Oct 2014, P. 224-229.

[7] Auke J. Ijspeert. Biorobotics: Using robots to emulate and investigate agile locomotion. Science, 10 Oct 2014, P. 196-203.

[8] Uluc Saranli, Martin Buehler, Daniel E. Koditschek. RHex: A Simple and Highly Mobile Hexapod Robot. The International Journal of Robotics Research. Vol 20, Issue 7, pp. 616 - 631, July 1, 2001.

[9] A. Ferworn, C. Wright, J. Tran, C. Li and H. Choset, "Dog and snake marsupial cooperation for urban search and rescue deployment," 2012 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR), College Station, TX, 2012, pp. 1-5.

[10] National Centre of Competence in Research (NCCR), 2017. [Online]. Available: http://www.nccr-robotics.ch/RescueRobots

[11] T. Horvat, K. Melo, and A. J. Ijspeert, "Spine Controller for a Sprawling Posture Robot," IEEE Robotics and Automation Letters, 2017.

[12] Spy in the Wild, BBC One original series, 2017. [Online]. Available: http://www.bbc.co.uk/programmes/b088t67m