# Using a Biological Material to Improve Locomotion of Hexapod Robots

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**Abstract.** Animals can move in not only elegant but also energy efficient ways. Their skin is one of the key components for this achievement. It provides a proper friction for forward motion and can protect them from slipping on a surface during locomotion. Inspired by this, we applied real shark skin to the foot soles of our hexapod robot AMOS. The material is formed to cover each foot of AMOS. Due to shark skin texture which has asymmetric profile inducing frictional anisotropy, this feature allows AMOS to grip specific surfaces and effectively locomote without slipping. Using real-time walking experiments, this study shows that implementing the biological material on the robot can reduce energy consumption while walking up a steep slope covered by carpets or other felt-like or rough substrates.

**Key words:** Shark skin, Biomechanics, Walking robots, Frictional anisotropy

Animals show fascinating locomotor abilities. They are able to traverse a wide range of surfaces in an energy efficient manner. During traversing, their locomotion can also adapt to a change of terrain. In addition, their movements are elegant and versatile. Biological studies reveal that these capabilities are the result of a combination of neural control and biomechanics including proper material properties [1]. While neural control generates movement and allows for adaptation, biomechanics provides shape, support, stability, and movement to the body as well as enables energy efficient locomotion without high control effort. Over the past decade, roboticists have tried to mimic such natural features with their artificial systems [2,3] in order to approach animals in their levels of performance and to understand the functions of their biomechanics and neural mechanisms. To tackle this challenging problem towards animal-like locomotor abilities, we have developed the AMOS series of biologically-inspired hexapod robots, in a stepwise manner during the last years [4]. AMOS (Fig. 1a, left) has now achieved a multitude of different walking patterns as well as adaptable locomotion [4]. It is under real-time neural control by ways of a modular neural network allowing it to walk at different gaits and adapt its locomotion to traverse rough terrains, or to climb over obstacles [4]. Although AMOS has shown a certain degree of complex locomotor behavior under neural control, it still requires very high energy consumption to walk up a steep slope (e.g., a 17° slope covered by carpets). During walking up the slope, its legs slip since its rubber feet do not provide enough adhesive friction. Thus, a central question of this work is "Can we improve the locomotion of AMOS during walking on specific terrains (i.e., slope covered by carpets or other felt-like or rough substrates) without high control effort?"

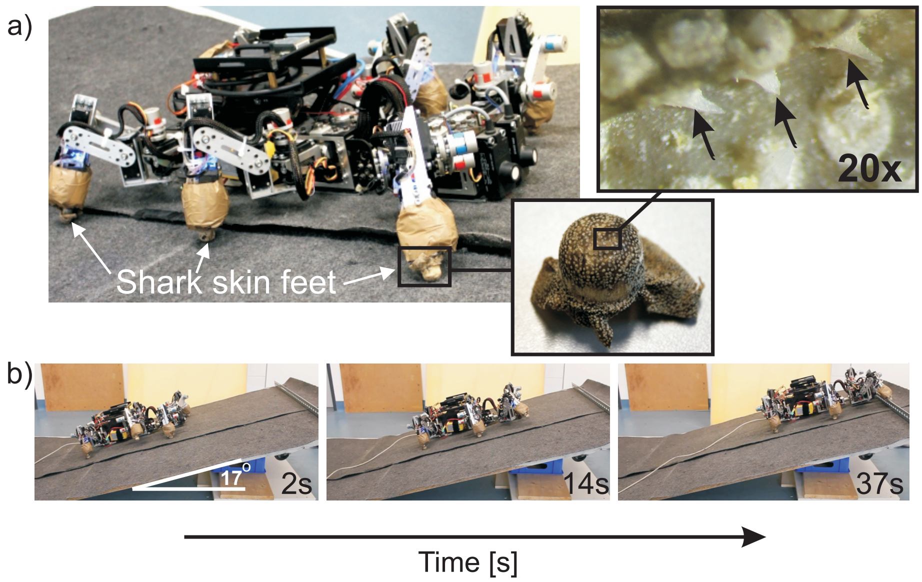


**Fig. 1.** (a) The hexapod robot AMOS with basking shark skin feet. Zoom panels show a shark skin foot formed to cover a rubber foot and a close up view (20X) of basking shark skin texture taken from a microscope. The basking shark skin has asymmetric profile like a sloped array of spines. (b) Snap shots of walking up a 17° slope covered by carpets where AMOS uses the shark skin feet.

To answer this question, in this study we have investigated different types of materials including biological ones (e.g., polishing papers, the skin of harbor seal (Phoca vitulina), and the skin of basking shark (Cetorhinus maximus) at head area) for using them as feet of AMOS. Among them, the shark skin provides important features which are appropriate for the task. It has texture having asymmetric profile (see Fig. 1a, right) which induces frictional anisotropy. This way, it acts as a locking mechanism which can prohibit slipping motion. In addition, it can be easily formed to have a cup-like shape (see Fig. 1a, middle) such that we can simply attach it to AMOS' foot. Shark skin feet were prepared from hydrated shark skin tightly pressed in a negative wooden form resembling the geometry of the robot feet. Shark skin was then dried for several days and remained stable in the robot feet geometry after removal from the form.

To evaluate the performance of the shark skin feet, we covered original rubber feet of AMOS by the shark skin feet (see Fig. 1a, left) and let AMOS walk with a wave gait up a $17^\circ$ slope covered by carpets. Note that this angle is steep enough making AMOS difficult to walk up using its rubber feet. We performed five runs each and then compared walking efficiency using the shark skin feet with the one using the rubber feet. Here, the walking efficiency is measured by the specific resistance given by: $\epsilon = \frac{P}{mgV}$, where $P$ is power consumption, $mg$ is the weight of AMOS, i.e., 56.84 N, and $V$ is walking speed. Low $\epsilon$ corresponds to highly efficient walking. An illustration of real-time walking experiments is shown as snap shots in Fig. 1b. We encourage readers to also see the video of AMOS walking behavior using the shark skin feet and the rubber feet at http://manoonpong.com/LM2013/S1.wmv. The average specific resistances with standard deviations of AMOS walking using the shark skin feet and the rubber feet from five runs each are 48.56±19.3 and 168.61±18.43, respectively. The experimental result shows that using the shark skin feet leads to low specific resistance, thereby highly efficient walking compared to the rubber feet. Due to the special shark skin profile (see Fig. 1a, right), it allows AMOS to grip specific surfaces (i.e., carpets, felt-like, and rough surfaces) and effectively locomote without slipping. This preliminary result reveals that utilizing material with strong frictional anisotropy can improve robot locomotion without modifying a controller. Although the shark skin feet show a good performance and improve robot locomotion, they are still less robust compared to the rubber feet since the profile of the shark skin feet was destroyed after a few successive runs. In our next step, we will investigate and create synthetic nano-structured surfaces that attempt to mimic aspects of the shark skin system for robot feet while being robust to prolonged usage. **Acknowledgments:** This research was supported by the Emmy Noether Program (DFG, MA4464/3-1) and BCCN II Göttingen (01GQ1005A, project D1). We thank Anja Huss for producing a close-up view of the shark skin and Joachim Oesert for technical assistance.

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