Towards amphibious locomotion with Cheetah-Cub-AL

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1 Introduction

Terrestrial, aquatic and aerial locomotion for robots are normally researched separately. Due to the fact that many of the animals we are inspired from, specialize in one certain field, developed robots excel in a single area and help us understand biological aspects better and more profoundly [1]. However, if we look closer, we realize that the versatility of animals is not restricted to their preferred habitat. With some exceptions, they are capable of using at least one other form of locomotion, sometimes very proficient or just enough to survive in critical situations. Coming from the world of quadrupedal terrestrial locomotion, our interest is the expansion to the aquatic realm. Cats, dogs, horses and many other terrestrial, quadrupedal animals are capable of swimming or at least of aquatic stepping. These animals adapt their terrestrial gaits when in water, just like amphibious animals that adapt their swimming motion to move on land [2]. Furthermore, animals have the ability to rather quickly adapt to limb loss and generate new locomotion strategies. It would be very interesting to investigate if said adaptation is fundamentally the same on land and in water or if it differs greatly. Our motivation is to develop a robot that can mimic natural behavior in different environments, not only limited to creating better and more focused insights on biology, but also advancing technology to be more field ready. Especially our interest in search and rescue, where the environmental conditions are not controllable, rises the need for more versatile robots.

Figure 1: Examples of primarily terrestrial or aquatic quadrupedal mammals, which are able to locomote in both environments; Sea Otter [3], Biever [4] and Cat [5]

2 Locomotion in water: insights from nature and robotics

Nature: Literature about swimming cats, rats, dogs, sea otters and other animals which are known for their good performance on land and water give insight on the respective gaits used in both environments. One main distinction has to be made. Some animals prefer swimming over walking and are considered primary swimmers (e.g. the sea otter) and some hold it the other way around, making them primary walkers, e.g. dogs, cats and rats. This influences which primary gait is modified to be used in the other environment. Also many physiological characteristics, such as a streamline form of the body and specific weight distribution are influenced by the preferred habitat [6]. Although not yet completed, our current literature analysis tends to support the hypothesis that primary walkers rather use the same motion pattern on land and in water. The adaptation takes place in modulation of their motion frequency and amplitudes, as well as the duty factor, shown by [7] in the case of cats. Primary swimmers however often also adapt their physiology to match their habitat. Thus they use a strongly articulated spine to employ anguilliform swimming that grants them high maneuverability at medium speeds [8, 6]. These animals tend to modulate their spines traveling wave during swimming towards a standing wave for walking [2]. Unfortunately and so far, we could not find any literature about shallow water stepping for animals other than the salamander [9]. Thus we will exclude it for the moment. Our preliminary findings confirm the feasibility of using an existing quadruped robot with small modifications of the terrestrial gait or adaptation of the control strategy to generate deeper knowledge of quadrupedal, mammalian swimming.
Robotics: Existing aquatic or amphibious robots such as Amphibot [2], Pleurobot [9], Aqua [10], Little Crabster [11] or ACM-R5 [12] deploy different methods of locomotion in water ranging from walking on the sea floor to anguilliform swimming in three dimensions. Including the high variety of fish like robots mentioned in [8], even more locomotion strategies appear. One aspect is very common in all the robots mentioned: They are all inspired by animals that either adapt serpentine like structure in the spine and/ or are primary swimmers. The most popular solution for waterproofing is the construction of a rigid casing around sensitive parts. Pleurobot is an exception, using a flexible suit, but with limited success. Encasement of the sensitive parts with a rigid shell and sealing any moving parts watertight seems thus the most promising waterproofing strategy.

3 Waterproofing Cheetah-Cub-AL

Addressing the challenge of submersing a water-sensitive piece of technology is never an easy task. Small failure of water proofing can lead to fatal damage to the robot. In this case, the basic conditions to achieve such a water proofing with Cheetah-Cub-AL are rather promising, and will be discussed in the following. The leg-design of Cheetah-Cub-AL features a spring loaded pantograph leg

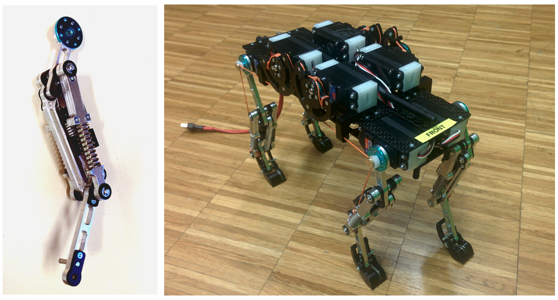

Figure 2: ASLP-leg and Cheetah-Cub-AL from isometric views

with two symmetric diagonal springs, canceling unwanted bending behavior present in previous leg versions. Each leg is driven by two proximally located motors, one invoking pro and retraction directly at hip level and one compressing the knee through a bouden cable. Knee extension is achieved passively via the diagonal springs. Making use of classical CNC-manufacturing techniques with aluminum, movement of the whole leg submersed in water is feasible without additional protection. The compact trunk holds all electronics and motors of the robot. Fig. 3 shows the water proof casing developed to protect the water sensitive elements. The casing consists of three main parts: 1) the two symmetrical shells are tightened together with screws and a rubber seal; 2) heat sinks located above their respective motors and 3) axis extenders embedded in rotational water proof seals, for transmission of motor torque to the legs, widening the robot by 70mm.

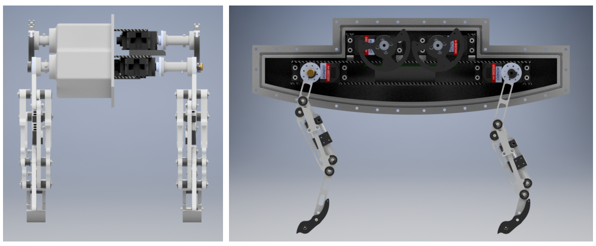

Figure 3: Rendering of the swimming cheetah with half open casing in front and side view

We chose to use two symmetrical shells to maintain and easy mounting and unmounting procedure for the robot. As Cheetah-Cub-AL will not only be used in water, the additional weight ($m = 400g$) of the shell might hinder it to achieve its maximum performance and agility on land. Additionally, easy access to the control board remains feasible. By embedding heat sinks outside the shells and using flowing water as a natural cooling system, we can potentially solve the problem of heat generated by the motors in the casing. We use the motors in an oscillatory motion which generates high jerk and consequently quick heating. Without the heat sinks, failure of the robot would have been almost assured. The axis extenders make a switch between configurations with and without casing feasible. This enables exploration of more rare locomotion cases, e.g. swimming of a quadruped with an amputated limb. With this simple design, which just completed a successful 48h underwater test without the robot, an exploration of aquatic or semi-aquatic gaits becomes possible.

4 Conclusion and Acknowledgement

We presented our initial ideas in researching aquatic locomotion with cat like robots and its implications for biology. The implementation on the robot and results achieved from an extensive experimental study will allow to drive the development of amphibious quadruped robots further and eventually apply them in the field of search and rescue robotics.

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