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Bioinspired robots for seabed operations

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***Abstract*— To transform and improve the current approach of underwater robotic exploration, we took as a reference benthic marine animals with the aim of unveiling the principles behind their agile legged locomotion. Rather than avoid contacts with the environment as traditional underwater robots do, our robots exploit the interactions to obtain swift and accurate movements. Our approach has the aim of pioneering a new breed of underwater vehicles which can move over underwater structures without disturbing the environment, and could perform muscular works when needed.**

Keywords—underwater robotics, legged robotics, soft robotics

I. INTRODUCTION

Broadly speaking, underwater robots fit into two main categories: autonomous underwater vehicles (AUV), which are usually torpedo-like robots used in large area surveys, and remotely operated vehicles (ROV), which are usually box-shaped robots controlled by human operators to perform inspection and interaction tasks. Despite the great successes obtained so far, the working space of current underwater robots is limited. In particular, whenever precise interactions with the environment are required (e.g. collection of specimens, sampling of sediments, high resolution photography, underwater caves inspection, wreckage inspection, etc.) the complexity of the operation increases dramatically, possibly preventing its accomplishment [1], [2].
Recognized as one of the Grand Challenge of Science Robotics [3], navigation and exploration in extreme, unmapped, environments are the typical duties of underwater robots. Physical robustness to resist to harsh, dynamic environments, dexterous manipulation, high payload, user-friendly control, and context awareness are just a few examples of the features wanted by an underwater system [4]. Researchers made amazing progresses to tackle the extreme conditions underwater robots are subjects to, also considering that the physical properties of water prevent the transfer of most of the technological advancements obtained in aerial or ground vehicles. However, we could notice recurrent sentences in foreseen developments of underwater vehicles, like: "ROVs need to be more powerful; battery duration and power density should be improved; computing power and sensor capabilities should be increased" [5], [6]. The research approaches followed so far (which rely mostly on technological improvements or on novel algorithms) realize specific and significant technological steps which move forward the underwater robotics field.
Underwater robots are built upon a conceptual design which is almost unchanged since the first vehicle was developed almost 50 years ago. The harsh conditions imposed by the marine environment, altogether with the difficulties on communications, control and reliability, limit the development of novel concept vehicles, which are starting to emerge just in the very recent years. If we compare the variety of terrestrial and aerial robots with the marine one, we will be startled by the apparent uniformity of the latter. This is not a simple matter of diversity: the role of the body in cognitive, adaptive, and locomotion tasks is clearly recognized as pivotal in the development of intelligent and reliable behaviours in unknown environments [7], [8].
A conceptual shift is ongoing in robotics where the burden of control is currently shared among the brain (microprocessors, computers, etc.) and the body (natural dynamics, body compliance, etc.) [16]. Self-stabilizing systems proved their effectiveness in complex tasks like motion in unstructured environments [9]; adaptive arms and end-effector simplified the control and manipulation of delicate and complex objects [10], [11]; and interactive behaviours grant resilience to damages [12]. These examples invite to build machines which exploit the interaction with the surrounding environment to increase their capabilities, which is exactly where underwater robotics is struggling. To take benefit of this novel concept, the field has to do a significant step in a different direction, complementing the results obtained so far with novel concept vehicles.
Underwater robotics reached a technological maturity which invites the applications of completely novel approaches, by changing the scientific quest from: "How can I improve my robot to achieve better autonomy, control, and interaction capabilities?" to: "How can I design a new robot to achieve better autonomy, control, and interaction capabilities?".

II. UNDERWATER LEGGED ROBOTICS

By building upon these premises, our idea is to take benefit of seabed locomotion but using propulsive means different than wheels or tracks. During the past decades, scientists and researchers put significant efforts at creating robots which can move as animals do, with similar agility, speed, and stability. Legged robotics has a paramount role on this mobility quest, and it employed multi-disciplinary efforts including biological studies [13], mathematical modelling [14], artificial intelligence approaches [15], [16], mechanical optimization [17], and many others. Underwater legged robots (ULR) potentially enable locomotion on rocks, precise positioning of foot or agile pushes when required; a stable platform for manipulation, inspection, and interaction; an overall reduction of energy consumption on station keeping. Due to the difficulties of a novel conceptual design in such a harsh environment, we want to apply a bioinspired approach for the distillation of fundamental principles of underwater legged locomotion, and eventually build a novel robot for sea exploration which will enlarge the capabilities of current underwater robots

A. *From octopuses crawling to crabs punting*

The first attempt to create an underwater robot with locomotion and grasping capabilities was performed by the authors' studies on the *Octopus vulgaris*. Biological investigations led to the discovery of simplifications both on the single arm movements, and on the coordination of multiple arms. The octopus employs a repeated sequence of actions to push the body forward [18], and that combination of multiple arms are used to change locomotion direction [19].

This study led to the formalization of a fundamental model, called Underwater Spring Loaded Inverted Pendulum (U-SLIP) which abstracted body shape [20], legs compliance and actuation strategy to obtain a generic framework upon which more complex control design and control strategies could be developed [21]. By taking as a reference such biological findings, single and multi-legged robots were developed.

III. Single and Multi-legged prototypes

The validity of the model was tested on a robotic platform which comprised a single leg and a body with a defined shape. The self-stabilization features of the system, which allowed by using hopping locomotion to transverse several complex ground without prior knowledge neither a different control law [22], was the building block to prove the effectiveness and resilience of such system for underwater exploration. Moreover, the role of the body was investigated in the context of shape-changing structures, which highlighted how morphology itself could be exploited to stabilize robotic systems by exploiting shape dependent forces [23].

The development of multi-legged system granted both static stability and agility of locomotion. As for the original Spring Loaded Inverted Pendulum model, also in this case the U-SLIP model could be employed to describe (and thus design) multi-legged system [24]. Thanks to the high degree of self-stabilization, the robot was able to hop over complex and uneven grounds.

IV. Conclusion

Thanks to a bioinspired approach and the formalization of a generic fundamental model, new concept vehicles can be developed which have the potential to increase the exploration capabilities of traditional underwater vehicles. The low energy consumption, the small disturbances to the ground and the agility of locomotion elect them as perfect tool for delicate sampling and monitoring operations [25].

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