

Chapter 6

State of the Art in Biomimetic Swimming Robots: Design Principles and Case Study

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ABSTRACT

The presence of marine tasks demands investments on design and development of underwater robots. Among those robots, biomimetic swimming robots have shown superior performance since they are efficient in cruising, highly manoeuvrable, and noiseless during swimming. Accordingly, so far a number of fish robots with distinguished capabilities have been fabricated around the globe. The difference of the existing fish robots roots in their unlike but optimal nature of swimming. Hence, in order to design fish robots, the swimming characteristics of real fish including swimming mode and body/fin shape must be investigated primarily. Then the appropriate actuation system needs to be selected. This chapter aims at presenting state of the art in robotic fish while introducing their design elements and presenting suitable actuation mechanisms for fish robots. In this chapter, a fish robot is introduced and its design process is discussed as a case study.

INTRODUCTION

Undersea operation, oceanic supervision, aquatic life-form observation, pollution search and military detection are just a few examples that demand development of underwater robots to replace humans (Junzhi Yu, Tan, Wang, & Chen, 2004). Here biomimetics plays a significant role as the best ideas inspired from the nature have been widely applied to address many scientific issues (Habib, 2011). Accordingly, a

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number of bio-inspired robots such as fish robots have been developed so far (Ayers, Davis, & Rudolph, 2002; Bar-Cohen & Breazeal, 2003; Kato & Kamimura, 2008; Paulson, 2004).

Among underwater robots, biomimetic swimming robots have shown superior performance in comparison to screw propeller underwater robots. This superiority roots in the efficient cruising, manoeuvrability and noiseless motion of biomimetic swimming robots¹ which are defined as fish-like aquatic vehicles which propel through undulatory or oscillatory motion of either body or fins (Huosheng Hu, Jindong Liu, I. Dukes, & G. Francis, 2006). For instance, the propulsion system for some types of fishes is up to 90 percent efficient, while a conventional screw propeller is around 40 to 50 percent efficient (Junzhi Yu & Wang, 2005). Due to the capabilities of biomimetic swimming robots, they have been employed for various applications (H. Hu, Oyekan, & Gu, 2012; Marras & Porfiri, 2012; Polverino, Abaid, Kopman, Macri, & Porfiri, 2012; H. Yu, Shen, & Peng, 2012).

A fish robot is defined as a fish-like aquatic vehicle which propels through undulatory or oscillatory motion of either body or fins. The first fish robot, RoboTuna, was built at MIT in 1994 (M. S. Triantafyllou & Triantafyllou, 1995). Three years later, Vorticity Control Unmanned Undersea Vehicle (VCUUV) was developed based on RoboTuna with some improvement and more capabilities such as avoiding obstacles and having up-down motion (Anderson & Chhabra, 2002; Liu & Hu, 2004). Afterwards, a number of institutes and universities developed their own fish robots with various capabilities such as cruising and turning by pectoral fins (Lachat, Crespi, & Ijspeert, 2005), cruising by undulating anal fins (K. Low, 2009) and so on.

The distinguishable capabilities and swimming performance of the fish robots root in their unlike inspiring fishes. Depending on the nature of fish and their living habitats, fishes have optimal but diverse swimming characteristics which are made through their swimming mode and, body/fin shape. Accordingly, in order to develop a biomimetic swimming robot, beside its actuation mechanism, its swimming characteristics must be investigated. This chapter aims at presenting state of the art in robotic fishes and introducing the required features for the development of biomimetic swimming robots including swimming mode, body and fin shape and actuation mechanism.

The remainder of this chapter has four sections. Section 2 categorizes the existing biomimetic robots within their corresponding swimming modes. Section 3 discusses the body and fin shape of fishes with respect to their swimming forces. In the next section, the actuation systems that are employed for fish robots are presented. Section 4 introduces a tuna-mimetic robot and discusses its design criteria as a case study. In the last section, the chapter is concluded.

Existing Fish Robots

Fishes propel through either undulatory or oscillatory motion of different parts of the body or fins which is called propulsors. The fish body, caudal fin, median and paired fins are the propulsors of fishes that are presented in Figure 1.

In oscillation case, a fish oscillates a certain part of its body around its base like the motion of a simple pendulum. On the other hand, in undulation case, a number of fishes generate propulsive waves by making travelling waves using their bodies or fins at a speed greater than the overall swimming speed of the fish. The tail and the fin of the fish, shown in Figure 2, are generating an undulatory motion. In some types of fish like lamprey, the whole body participates in generation of motion. If this travelling wave has a speed greater than swimming speed of the fish, the fish goes forward, and vice versa (Sfakiotakis et al., 1999b).

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