［様式－学 5］

Abstract of Doctoral Thesis

Title：Evaluation of Locomotion Performance for a Wheel-Paddle Robot

Doctoral Program in Advanced Mechanical Engineering and Robotics
Graduate School of Science and Engineering
Ritsumeikan University

シェン　ヤイ
SHEN Yayi

To help the human beings conducting search and rescue tasks after disasters, the eccentric paddle mechanism was proposed for robot to access amphibious terrains. The design concept is to balance the advantages and disadvantages in both wheeled robot and legged robot, so as to improve the mobility. The reconfigurability of the eccentric paddle mechanism endows the robot with high adaptability in different situations. Previous work has analyzed the motion modes on a single module prototype. In this thesis, we evaluate the locomotion performance of a robot that is composed of four eccentric paddle modules.

First, a robot prototype that consists of four wheel-paddle modules has been designed and fabricated. Considering the severe environment that the robot will be sent to, necessary protection measures such as waterproof and sandproof schemes are adopted. Besides, a complete control system has been constructed, including hardware and software.

Based on the new fabricated robot prototype, a hybrid locomotion mode is proposed for traversing terrestrial terrains, which include normal flat floor, rough grass, big stones, small gravels, or even soft terrain like sand. The reason of using this hybrid mode is that the previous legged modes were only suitable for flat ground, but can not be applied to rough terrains directly. And comparing with them, the hybrid mode is easier to be controlled. While dealing with variable terrain situations, the configuration of the wheel-paddle can be transformed quickly among wheel-support, hybrid-support and paddle-support by only adjusting the location of the paddle shaft. And during usual locomotion, only the wheel is actuated to generate traction force, which is more efficient.

The robot performing with the hybrid mode is primarily verified in rigid terrains, including three normal rough terrains (grass, stone, gravel) and one flat terrain (floor). It is found that the robot consumes more energy in rough terrains. But comparing with previous legged modes, the efficiency of the hybrid mode in rough terrains is similar with the legged modes on flat ground. In addition, the locomotion speed is increased, which is near one body length per second.

Then, the trafficability of the robot with hybrid mode in sand is investigated particularly due to the special properties of soft terrain, which makes the interaction between the robot and the terrain more complex and variable. First the paddle terredynamics is studied theoretically and experimentally. The results have shown that longer protruding length of the paddles can generate larger traction force. To find out how the protruding paddle length affects the locomotion performance, an indoor testbed that allows one wheel-paddle module moving freely in horizontal and vertical directions is built. It is found that the wheel-support configuration is easy to slip at high locomotion speeds, while the protruding paddles have effectively reduced the slippage and increased the efficiency. The locomotion performance of the whole robot in outdoor sand is also evaluated. The locomotion speed increases with the rotational speed of the wheel, while the efficiency tends to be better at higher locomotion speed. From the evaluation in both indoor testbed and outdoor field, it is found that the system inertia and the sand properties affect the slippage and sinkage between the robot and the soft terrain, so as to affect the locomotion performance.

At last, the propulsion performance of one wheel-paddle module with different swimming modes are explored. The hydrodynamic forces generated by the oscillating paddling mode (fish-like) and the rotational paddling mode (propeller-like) are compared theoretically and experimentally. The results have shown that the rotational mode is superior in generating large amplitude of thrust, while the oscillating mode is more efficient. Both of them can produce linear directional thrust when adjusting the location of the paddle shaft. However, large negative thrust was found in oscillating mode, which is a waste of energy. To further enlarge the thrust amplitude in oscillating mode and increase the propulsion efficiency, a novel front crawl stroke (human-inspired) is proposed. It is verified that the front crawl stroke can generate more than three times net thrust than the oscillating mode, and has increased the propulsion efficiency as well.

The evaluation of the locomotion performance has further verified the mobility and adaptability of the configurable wheel-paddle robot in various field terrains. It also inspires the future work towards real application in amphibious environment.