Available online at www.sciencedirect.com
ScienceDirect
Journal of Bionic Engineering 11 (2014) 459–468

Prototype Design and Experimental Study on Locust Air-Posture Righting

Diansheng Chen, Junmao Yin, Kewei Chen, Kai Zhao, Benguang Zhang

Robotics Institute, *Beihang University*, *Beijing* 100191, *P. R. China*

Abstract

Locust has the capacity to maintain a righting posture and glide through attitude adjustment after leaping. A prototype inspired by the dynamic mechanism of attitude adjustment of locusts was developed. The prototype consists of a pair of wings driven by a four-bar mechanism, and a 2 Degree of Freedom (DOF) tail to imitate the movement of the locust abdomen. The power source, microcontroller, wireless data transmission module, and attitude sensors are contained in the fuselage. Experiments imitating the flight of locust were conducted to determine the mechanism of locust Subsequent Attitude Adjustment (SAA). The tethered prototype was driven by the movement of the tail and the flapping of the wings. Results show that the pitch and yaw of the tail, and the asymmetric action of the flapping wings significantly influence the posture of the prototype. These findings suggest that both the wiggling abdomen and flapping wings contribute to the locust SAA in the air. This research lays the groundwork and technical support for the probable design and development of practical jumping robots with attitude adjustment function.

Keywords: attitude adjustment, locust air-posture righting, prototype design, wiggling tail, flapping wing

doi: 10.1016/S1672-6529(14)60058-5

1 Introduction

The high over-obstacle characteristic of a hopping robot can efficiently solve the difficult problem of overcoming obstacles for micro robots. This characteristic equips the hopping robot to have a broad application prospect in many fields, including space exploration, military surveillance and anti-terrorism. The National Aeronautics and Space Administration (NASA) first developed a bouncing mechanism for lunar exploration in 1969[1]. The Boston Dynamics recently developed the Sand Flea, which can jump 30 feet into the air to overcome obstacles[2]. However, all jumping robots encounter unavoidable tumble and unexpected attitude in air, which result in uncontrollable landing attitude.

The method by which to ensure stable robot posture to enhance the jumping distance or to land with the correct attitude is a very fundamental and innovative research topic. Three steps were proposed to determine the attitude adjustment of locusts. The first step is the regulation of the jumping gesture, followed by adjustment of the attitude in the air, and finally, the acquisition of the posture recovery after landing. The locust can stabilize its posture in the air after takeoff and then land without overturning. These capabilities of locusts attract the interest of many researchers and organizations. Cofer *et al*. proposed that the locusts control tumbling during their jump by two mechanisms. The first mechanism is that the locusts adjust the pitch of their body to move the center of mass closer to the intended thrust vector. The other mechanism is that the locusts contract their muscles during the jump to produce torques that counter the torque produced by thrust[3]. Han *et al*. observed the jump gestures of locusts and discovered that trajectory control is achieved through the rapid rolling and yawing movements of the locust body caused by the forelegs, midlegs and hindlegs in different jumping phases[4]. Substantial research laid the groundwork for the probable control of the robot attitude[5–7]. Controlling robot jumping posture, however, was difficult. Some researchers studied the dynamic flight stability of locusts and determined the influence of flapping wings on locust air posture[8]. These works established the basic bionic principle for air-stability in jumping robot research. Scarfogliero *et al*. built a hopping robot called Grillo and presented the idea that wings can be used to extend jump

Corresponding author: Diansheng Chen
E-mail: chends@buaa.edu.cn

hangtime, increase jumping distance, and lengthen tails to adjust gliding direction[9]. Kovač *et al*. comparatively analyzed the wing configuration of bats, butterflies, and locusts, and designed a folding wing and empennage installed on a miniature hopper to achieve glide and direction adjustment[10–11]. Nguyen and Park studied a 7 g prototype of locust-inspired jumping mechanism concentrated on mimicking the locust leg structure in terms of driving muscles. They conducted jumping tests to characterize the jumping performance of locusts and their stability after takeoff; the integration of a wing folding/unfolding mechanism for a longer jumping distance and safe landing were considered key to further work[12]. Phan *et al*. also designed an insect-mimicking flapping-wing system and demonstrated that inherent pitching stability can be achieved for vertical takeoff by controlling the relative position between the center of gravity and the mean aerodynamic center of the flapping system[13]. Jumping-gliding is a practical multi-locomotion strategy. However, this method is confronted with a critical problem of the attitude transformation from tumbling to balance, which previous studies failed to clarify. Libby *et al*. studied lizards and suggested that active tail stabilization occurs during climbing, righting, and gliding[14]. A lizard-sized robot, with an active tail that used sensory feedback to stabilize pitch as it drove off a ramp, was built. However, this study is inapplicable to jumping robots. Kovač *et al*. presented a spherical system with a mass of 9.8 g and a diameter of 12 cm that can jump, right itself after landing, and jump again[15]. However, this system has complication with its huge size. Faisal and Matheson studied the predictable sequence of leg movement of a locust placed upside down on a flat surface to right itself[16]. This study provides the theoretical basis for the design of a self-righting jumping robot[17]. However, a strong impact seriously affects robot life and stability.

The air-righting method is one of the critical problems confronting a hopping robot. Only few studies have been conducted on the attitude adjustment of hopping robots in the air. This paper presents a prototype design and experiment, and provides technical support for the design of bio-inspired integrated jumping-gliding robot.

2 Morphological characteristics of the locust attitude adjustment

After a locust takes off, the inevitable rolling-over attitude and direction deflection depend on its morphology. The motion mode then changes into glide with proper and steady posture righting. The morphological characteristics are studied to reveal the principle and mechanism of locust attitude adjustment.

Locusts are good at jumping mainly because of their well-developed hind legs wrapped by a hard exoskeleton. Locusts can also jump and transform to glide steadily. The excellent aero attitude adjustment capability of locusts depends on their active and variable body and wings. The *Locusta migratoria manilens*, which is tawny with a length of approximately 40 mm, was selected for observation. Fig. 1 shows that the body of this kind of locust can be roughly divided into three parts, namely, the head, chest, and abdomen. The chest is the center of the movement, with two wings attached. The cutin forewings are narrow and tenacious, whereas the membranous underwings are wide and soft. The soft hybrid wing structure, which is composed of nervation and wing membrane, is flexible and lightweight, and is thus suitable for flight. These morphological features significantly enhance the aerodynamic characteristics of the flapping wing of locusts.

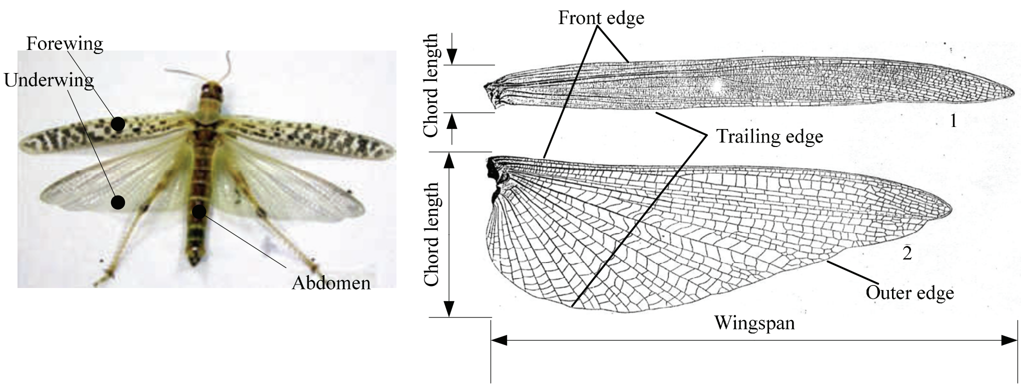

Fig. 1 Locust wings and surface structure.