# High-speed video analysis of jumping in *Locusta migratoria*

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## ABSTRACT

Among insects, locusts are widely recognized for their excellent jumping performances. Indeed, jumping helps locusts to avoid predators as well as to initiate flight. In the present contribution, we employed high-speed videos to analyze the jumping performance of *Locusta migratoria* L. from ground with different toughness. Results outlined that *L. migratoria* can prolong their takeoff time to get bigger takeoff velocity to adapt to different terrains, and takeoff velocity has no connection with takeoff angle.

Keywords: jumping performance, *L. migratoria*, simplified model, ground toughness

## INTRODUCTION

Due to the distinguished jumping ability of locust, there are numerous researches focused on locusts. Locusts have ability to control their jump performance by adjusting elevation angle, takeoff velocity and azimuth angle (*Sutton & Burrows, 2008*). Elevation angle is set by the orientation of the hindlegs relative to the body and is determined by the line connecting the distal end of a tibia with the proximal end of a femur (*Sutton & Burrows, 2008*). Takeoff velocity is controlled by using the extensor tibiae muscles to store and release the appropriate amount of energy within the elastic processes of a hindleg (*Bennet-Clark, 1975*). Azimuth angle is controlled by turning the body with the front and middle legs (*Santer et al., 2005*). Foreleg movements enable a locust to control its jump trajectory independent of the hindlegs motor program, allowing a decision on jump trajectory to be made after the hindlegs have been cocked in preparation for a jump. It is clear that locust can make targeted jumping to adapt to different situation while there are little reference about how locust adapt to different situations. Edward P. Snelling tested the effect of the temperature and body mass on the jumping performance by a serious of experiments which shows that temperature has no significant effect on the exponent of these relationships while jump energy in juvenile locusts increases disproportionately with body mass(*Snelling, Becker & Seymour, 2013*). In this paper, with the help of high speed video recording, a mathematical model is established to analyze the dynamics and jumping performance during takeoff phase of adults *L.migratoria.* The effect of the ground toughness on the jumping performance is investigated through comparing the takeoff time, velocity and elevation angle of a series of jumping from both tough foam plate and smooth acrylic plate. The relationships between different jumping parameters are surmised based on the experiment results.

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## Materials and Methods

*L. migratoria* adults were reared at Creative Engineering Design lab at the BioRobotics Institute of Scuola Superiore Sant'Anna of Pisa, Italy. Specimens were reared in the laboratory within cylindrical transparent plastic box (50 mm in diameter and 70mm in length) and fed with fresh vegetables and wheat. A total of 7 locusts are tested in our experiment for jumping behavior observation and video recordings. Temperature were maintained at 26±2℃ and relative humidity at 40±5% during experiments. The platform for locust jumping experiment is a foam box with size of about 30×20×30mm of which the front is a transparent acrylic board and the back is attached with coordinate paper. During the experiment a soft plastic bar was used to stimulate locusts to jump from a small hole at the upside of the foam box. The take-off phase videos were took using a HotShot 512 SC high-speed video camera(NAC Image Technology, Simi Valley，CA，USA), the highest frame rate of 8000 frame/sec). Sequential images from each jump were captured at a rate of 1000 frames/sec with an exposure time of 1ms. The HotShot 512 SC video camera stores images with a resolution of 512×512 pixels directly to its internal memory. These images were downloaded into a dedicated computer for data analysis. The area where insects were expected to jump was lit with four LED illuminators (RODER SRL, Oglianico, TO, Italy) that emit light (420 lm each) at k=628 nm. Red light was chosen both because it matches the maximum absorption frequency of the camera and because it does not damage the visual apparatus of the insects due to locusts do not possess receptors for that wavelength (*Bonsignori et al., 2013*).

Selected videos were edited with NAC HSSC Link software (NAC Image Technology) in order to contract the take-off portion from the whole video. Some videos were analyzed in advance with the native NAC software of the high-speed camera, which requires manual tracking of an area at a time. We chose ProAnalyst suite (Xcitex, Cambridge, MA, USA) software to track object movement and results show negligible errors in the trajectories of tracked areas.

Definitive video tracks were analyzed, using automatic tracking with ProAnalyst suite, to mark out the motion of the center situated between middle legs and hindlegs. The tracking methodology was based on the selection of a distinct feature and the determination of its frame-by-frame motion characteristics (i.e. position, velocity and acceleration) over time, with respect to the image plane. During automatic tracking, the user selects the feature location in a single initial frame. This feature is defined as a rectangular region of pixels in the initial frame. The software then examines subsequent frames and automatically finds and automatically tracks the feature. ProAnalyst suite software was carefully focally observed by operator to assure that the resultant auto-tracked paths corresponded to the actual raw image sequence. To avoid errors, we tracked every video four times and calculated average pixels of centroid during take-off.

We checked every chosen videos frame by frame and find the configuration just before the jump and defined this time as $t_0$ and define the end of take-off phase when hindlegs just lose contact with ground as $t_{fin}$. With the tracked centroid pixels of every videos and coordinate paper behind the platform behind locusts, we can easily change pixel positions into displacement in millimeter then we import those data into matlab and use the polynomial regression method to analyze data sets of trajectories and instantaneous velocities. The displacement coordinates were extracted from locust jumps whose trajectory lay in a plane very close to perpendicular with respect to the longitudinal axis of the video camera.

## Preliminary Results

High-speed videos are recorded to analyze the jumping performance of *Locusta migratoria Linnaeus* from ground with different toughness. By establishing a simplified theoretical model, we calculated *L. migratoria* normally can get 1.8318 m/s takeoff velocity and maximum acceleration about 66.72 $m/s^2$ with takeoff angle at about 36°.

Locusts are prone to slip when jumping from smooth ground especially for locusts with only one leg. The analyzed results show that locusts can prolong their takeoff time to get bigger takeoff velocity to adapt to different terrains, and takeoff velocity has no connection with takeoff angle while bigger takeoff angle have the possibility to help locusts to jump successfully with only one leg left or from smooth ground.

## Reference

**Bonsignori, G., Stefanini, C., Scarfogliero, U., Mintchev, S., Benelli, G., & Dario, P. 2013.** The green leafhopper, Cicadella viridis (Hemiptera, Auchenorrhyncha, Cicadellidae), jumps with near-constant acceleration. *Journal of Experimental Biology*. 216(7):1270-1279 DOI 10.1242/jeb.076083.

**Bennet-Clark H C. 1975.** The energetics of the jump of the locust Schistocerca gregaria. *Journal of Experimental Biology*. 63(1): 53-83.

**Santer R D, Yamawaki Y, Rind F C, et al. 2005.** Motor activity and trajectory control during escape jumping in the locust *Locusta migratoria*. *Journal of Comparative Physiology A*. 191(10): 965-975 DOI 10.1007/s00359-005-0023-3.

**Sutton G P, Burrows M. 2008.** The mechanics of elevation control in locust jumping. *Journal of Comparative Physiology A*. 194(6): 557-563 DOI 10.1007/s00359-008-0329-z.

**Snelling E P, Becker C L, Seymour R S. 2013.** The effects of temperature and body mass on jump performance of the locust *Locusta migratoria*. *PloS one*. 8(8): e72471 DOI 10.1371/journal.pone.0072471.