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Dominique Martinez

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Moth trajectories recorded with a lab-on-cables exhibit a Lévy flight pattern

Dominique Martinez^{1,2,*}

¹Université de Lorraine, CNRS, LORIA, 54000 Nancy, France

²ISM, CNRS, 13288 Marseille, France.

* Dominique.Martinez@loria.fr

INTRODUCTION/MOTIVATION

Despite their tiny brain, insects exhibit a rich behavioural repertoire in their daily life when foraging for food or searching for mates. Models of search processes are important not only to biology but also to applications in robotics. As an example, the characteristic “cast and surge” path of male moths tracking a pheromone source [1] led to an efficient search algorithm, named Infotaxis [2], which was successfully implemented in olfactory robots [3-4]. When external cues are available, Infotaxis exploits the scarcity of odour encounters to maximize information gain and thereby limit the search time. Yet, when no cue is present or before finding the first cue, random searches might be favoured for their lower computational cost. A special class of random walks, so-called Lévy flight, seems to be optimal for searching under restrictive conditions [5,6]. Lévy flights have been observed in many animals including humans but whether the trajectories of flying moths follow a Lévy distribution is largely unknown. This lack of knowledge is due in part to experimental difficulties in tracking moths of small size and high speed of motion. Here, we take advantage of a new technology, named lab-on-cables [7], to track free-flying moths and analyse their trajectories for correspondence with Lévy flights.

METHODS

To record free-flight trajectories we used a cable-driven robot, a.k.a. lab-on-cables [7]. Reminiscent of the SkyCam or SpiderCam [8] used to cover sports events, the lab rig supporting two cameras is mounted on cables and moves automatically with the insect (Fig. 1). The cables are actuated by motorized winches so as to keep the insect within the moving lab by minimizing the tracking error. The position of the moving lab is computed from the cable lengths. The position of the insect is computed by the embedded stereo-vision system and transmitted wireless to the control computer. To start an experiment, the insect is placed on a takeoff platform at the center of the moving lab. After takeoff, the robot tracks the insect within a workspace of 6 m long by 4 m wide and 3 m high and the insect trajectory is recorded. For analysis, the trajectories are described as a sequence of flight segments of relatively straight motion interspersed by abrupt turns. The turns are identified as changes in flight direction higher than a given threshold $\Delta\theta$. The empirical distribution $P(l)$ of the lengths l of the flight segments is plotted in logarithmic scale for correspondence with the theoretical Lévy flight distribution $P(l) \propto l^{-\mu}$. The power-law exponent μ is estimated with a linear fit in logarithmic scale and $\text{mean} \pm \text{SD}$ is obtained by averaging the results over different segmentation thresholds $\Delta\theta$.

RESULTS AND DISCUSSION

We recorded the trajectories of $n=32$ *Agrotis ipsilon* moths of $\sim 2\text{cm}$ long (Fig. 1 left). Moths flew at a relatively high speed (1-3 m/sec). Moth trajectories are well described by segments of straight flight punctuated by rapid reorientations (Fig. 2 left). The length of flight segments l in logarithmic scale spans over a limited range, i.e. 1-2 decades (Fig. 2 right). The distribution has a power law scaling $P(l) \propto l^{-\mu}$ reminiscent of Lévy flight with $1 < \mu \leq 3$. By varying the segmentation threshold $\Delta\theta$, from 10° to 50° , we estimate the scaling exponent $\mu \approx 2$ (1.94 ± 0.2 , mean \pm SD). The correspondence with Lévy strategies is striking given that a Lévy flight with $\mu = 2$ is optimal in the case of nondestructive targets [5] and performs better than Brownian strategies in the case of destructive moving targets [6]. When comparing our results with theoretical Lévy distribution however, we need to bear in mind that similarity in trajectories does not imply necessarily that the insect brain produces a Lévy search process. Yet, it is worth noting that $\mu \approx 2$ Lévy walks can emerge from autonomous patterns of neural activity in brain-blocked *Drosophila* larvae [9].

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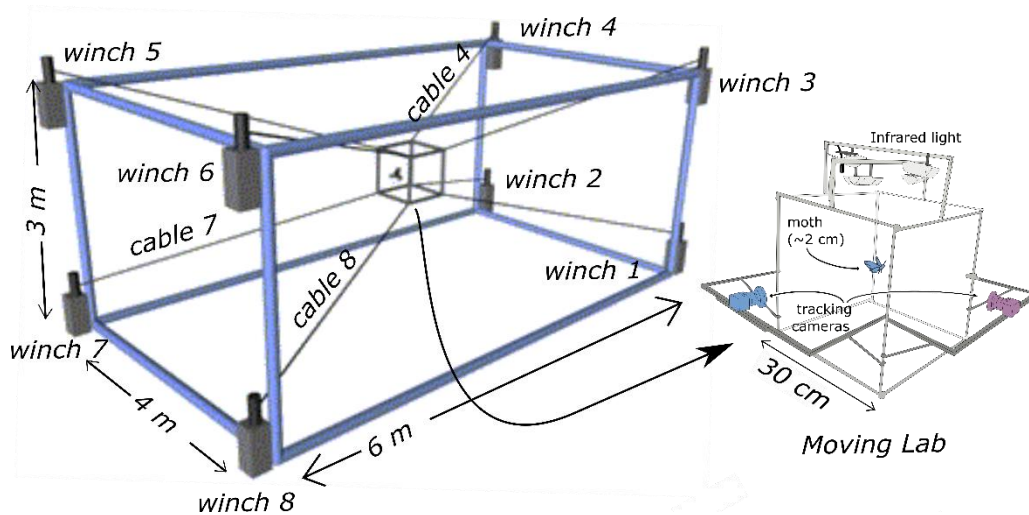


Figure 1. Collecting free-flight trajectories with a lab-on-cables. (Left) cable-driven robot for tracking free-flying insects in a workspace of 6m x 4m x 3m. (Right) Moving lab (30cm x 30cm x 30cm): Effector of the robot supporting the cameras and moving with the insect.

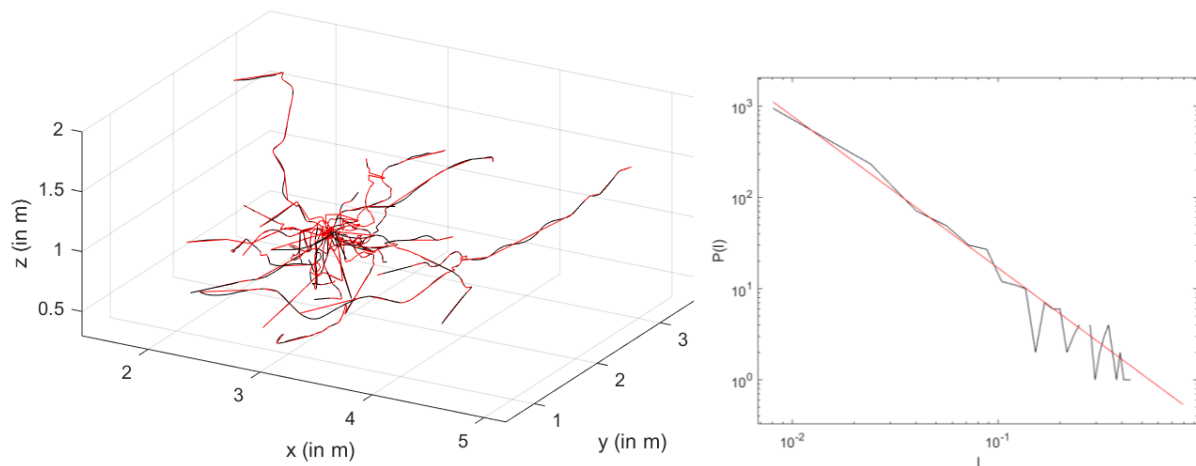


Figure 2. Correspondence with $\mu \approx 2$ Lévy Flights. (Left) Trajectories recorded with the lab-on-cables for $n=32$ moths. Raw trajectories are in black. Segmented trajectories are in red ($\Delta\theta = 10^\circ$). (Right) The empirical distribution $P(l)$ of the lengths l of the flight segments is in black. The linear fit with logarithmic scale is in red. The estimate of the exponent in $P(l) \propto l^{-\mu}$ is $\mu = 1.94 \pm 0.2$ (mean \pm SD).

Keywords: insect trajectory, Lab-on-cables, Lévy flight, search process, animal behaviour

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