KINEMATICS OF CATCHING ARMS IN INSECTS: TOWARDS OPTIMAL DESIGN OF ROBOTIC MANIPULATORS

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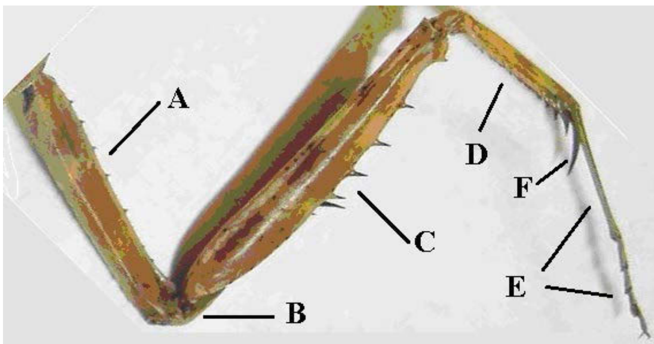
Construction of the running, jumping, swimming and burrowing legs in insects has been studied, while the catching hands in the predatory insects remain unstudied [1,2]. Anatomy and dynamics of the jumping and swimming legs have been used for biomimetic design of the corresponding robotic legs [3,4]. One of the known predatory insects is preying mantis (Mantidae family, order Mantodea) catching its prey by the 4-link forelegs (Fig.1a). In this study the morphology of the first pair of the legs of mantis fulfilling the function of catching prey arms has been studied for the biorobotic aims.

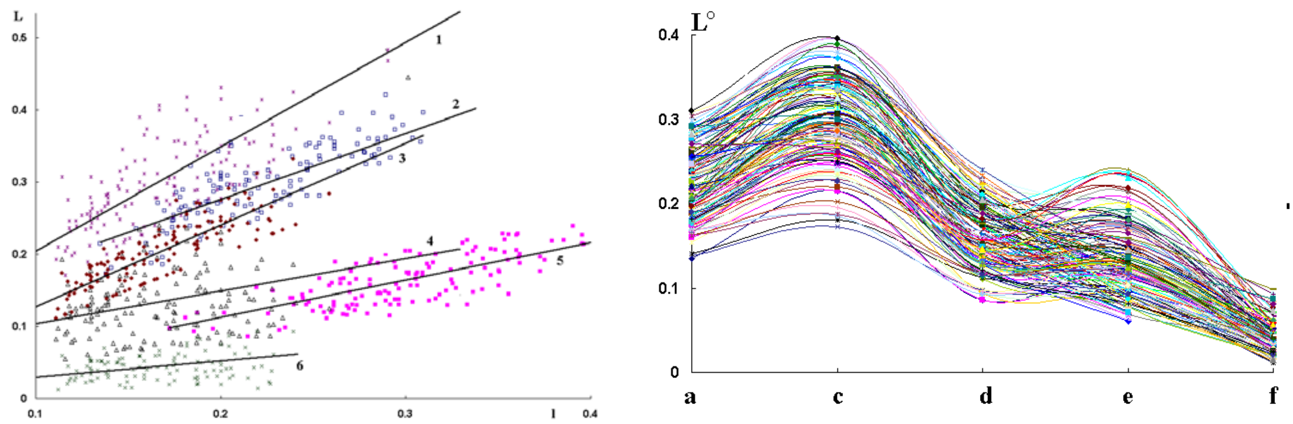
The lengths of the left and right forelegs (Fig.1b) have been measured on the ornithological collection of tropical and subtropical Mantidae. In total 382 male and female insects from 28 groups have been studied. To avoid influence of the specific size, the non-dimensional values have been computed as the ratio of the lengths of the segments A, C, D, E to the body length of the individual. A high correlation between the lengths of the adjacent segments has been found (Fig.2a), whereas the lengths of the non-adjacent segments had poor correlation. The length distributions of the non-dimensional lengths were similar in different groups of Mantidae (Fig.2b), while the cross-ratio (double ratio or anharmonic ratio) $AR = \frac{(l_{j-1}+l_j)(l_j+l_{j+1})}{l_j(l_{j-1}+l_j+l_{j+1})}$, which is an invariant in the projective geometry remains surprisingly constant for all the groups: $W_{ACD}=1.1 \pm 0.04$, $W_{CDE}=1.33 \pm 0.05$.

a



b

Fig.1. Capture of the prey by mantis (a), construction of the grasping arm (b): coxa (A), trochanter (B), femur (C), tibis (D), tarsus (E), claw (F).



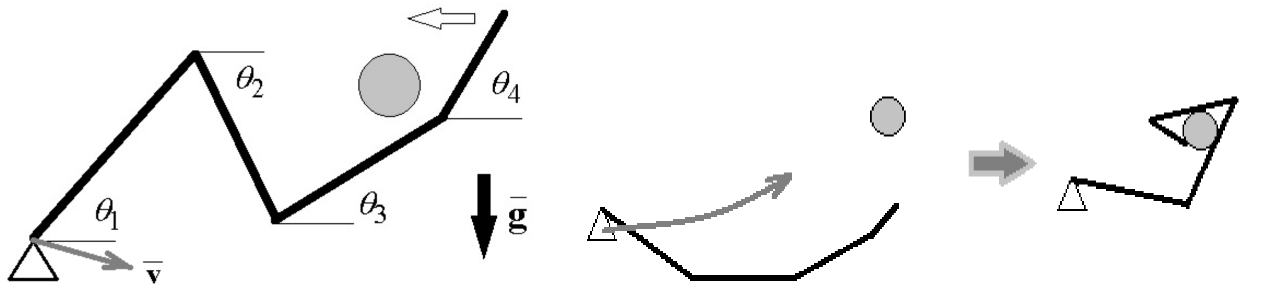
a b

Fig.2. Dependencies between the adjacent segments L and l (a): (D+E)(D) (1), C(A) (2), (D+F)(D) (3), E(D) (4), D(C) (5), F(D) (6); distribution of the non-dimensional lengths (b).

The obtained relationships have been used for biomimetic design of the 4-link catching hand (Fig.3a). Dynamics of the 4-link arm has been described by Lagrange equations

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{\theta}_j} - \frac{\partial T}{\partial \theta_j} + \frac{\partial \Pi}{\partial \theta_j} = Q_j, \tag{1}$$

where T and Π are kinetic and potential energy of the system, a dot over the symbol represents the time derivative, θ_j is the angle between the j-th segment and axis 0x, q_j is the net moment of force in the j-th joint. The angles have been set as $\theta_j(t) = \omega_j t$. The lengths of the arm have be taken from the measurement data averaged over the group studied (28 data sets). The prey has been modeled as a circle of diameter E/2 rapidly appeared and arbitrary moved from right to left. The neural network technology has been to teach the hand to catch the target. The sets of the dynamical parameters (ω_{1-4}, v_x, v_y) obtained for each geometry have been compared.



a b

Fig.3. The 4-link hand with 6 degrees of freedom (a) and the dynamics of catching the prey (b).

Efficiency of the motion has been estimated as the time T needed for the catching and the total energy ε spent for the capture. It was found, the optimal capture dynamics depend on initial location of the prey (height and distance to the base of the arm (triangles in Fig.3a,b), while the capture efficiency depends on the relationships between the segments. The best performance (min T, min ε) has been observed for the segments with W_{ACD}=1.2, W_{CDE}=1.3.

Basing on the obtained results, the biomimetic design for the 4-link robotic manipulator has been proposed. The manipulator has been useful for fast and efficient sampling of the moving individuals (insects, birds, fishes) for the research purposes.

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