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Titre de la thèse : Etude de l'équilibre postural des oiseaux

Along with humans, ten thousand species of birds adopt a strict bipedal posture. However, unlike humans, birds have a very stable equilibrium that allows them to sleep upright. This ability to maintain a bipedal posture while sleeping requires very little energy effort. This makes them a particularly interesting model for studying bipedalism. Studies often focus on movements but not on the passive posture of birds. This project focuses on balance and postural stability, based on the hypothesis that it is maintained by a tensegrity system.

Tensegrity is characterised by elements in tension (cables) with elements in compression (rods). In robotics, tensegrity is being studied to produce robots that are lighter and consume less energy. Birds have already inspired tensegrity robots, notably the Avineck robot [1].

The study of bio-inspired model focuses on reducing energy consumption through self-stability. Gaining a better understanding of birds' passive equilibrium could open up new perspectives in robotics: on the study of walking and even bipedal running.

We focused on studying the mathematical model of the bird's leg. Observations made in biology have made it possible to extract a simplified model of bird morphology based on the principle of a tensegrity system. Posture is maintained by the tension of cables and the effect of weight. The study [2] by A. Abourachid and C. Chevallereau showed that the robot cannot be stable with just one cable (which models the tendons of the bird's leg). Following this initial study, a model with four cables, which is as close to reality as possible while remaining as simple as possible, would enable a stable equilibrium to be obtained. It consists of four successive cables linking the trunk to the foot. It is made up of a bi-articular foot-ankle cable, two mono-articular cables, one at the ankle and one at the knee and a ligament loop behind the knee.

The aim of studying this model is to show the impact of the different parameters and and to extend the initial model to bird diversity. We will study an egret, a parrot, a zebra finch and a teal.

We consider the forces acting on the bird, gravity and the tension in the cables. First we look at the forces required to reach equilibrium to find the free length. We have seen the limitations of the four cables model, as the mallard, the egret and the macaw cannot reach equilibrium due to a negative force in the yellow cable. Based on our results, we propose a new model to simulate a wide range of avian pelvic limb proportions and determine the associated zone of stability, i.e. the zone within which the centre of mass (COM) can evolve while maintaining equilibrium. The aim is to compare, describe and identify the parameters that allow bipedal balance to be maintained in a stable and passive manner. We have also identified new elements needed in the maintenance of postural balance for all the leg proportions, such as a tendon at the front of the ankle that compensates for the negative force, and a tendon at the front of the foot that increases the bird's stability. Our results provide a better understanding of how birds maintain a stable bipedal posture and provide elements for the future development of bipedal robots.

[1] P. Wenger, B. Fasquelle, A. Abourachid, et C. Chevallereau, « Un robot en tenségrité inspiré du cou de l'oiseau ».
[2] A. Abourachid, C. Chevallereau, I. Pelletan, et P. Wenger, « An upright life, the postural stability of birds: a tensegrity system », doi: 10.1098/rsif.2023.0433.