Dinosaurs, Robots and Tails

Bruno Grossi and Javier Ruiz del Solar
Dept. of Electrical Engineering & Advanced Mining Technology Center (AMTC)
Universidad de Chile

Abstract—Modern birds are derived from a group of carnivorous bipedal dinosaurs known as theropods, with which they share many morphological characteristics [1-7]. For this reason cursorial birds have been widely used as models for understanding the locomotion of their non-avian ancestors (non - avian theropods) [8-11]. In our research we have demonstrated that chickens grown with artificial tails exhibit a kinematic locomotive response in their limbs similar to what we would have seen in their extinct ancestors [11]. Our results support the hypothesis that gradual changes in the location of the center of mass resulted in more crouched hind-limb postures, and a shift from hip-driven to knee-driven limb movements through theropod evolution. This suggests that, through careful experimental manipulations during the growth phase of ontogeny, extant birds can potentially be used to gain important insights into previously unexplored aspects of bipedal non-avian theropod locomotion.

The wide variability in body size and the existence of a heavy tail at the rear end of the body in certain dinosaurs, has generated controversy over the degree of maneuverability achieved by these animals, due to the biomechanical implications that a tail has in changes in the location of the center of the body mass and the distribution of mass around it. The tail could significantly change the moment of inertia of the body when the animal is turning during locomotion [10, 12-19]. These issues are being analyzed in our research work.

On the other hand, current birds exhibit a "head bobbing" motion during low speeds, which is characterized by a rapid forward thrust head movement, the latter helps stabilize their visual surroundings, which prevents the sensation of blurred images during head movement [20-24]. It is interesting to note that this bird's behavior has been used to understand the visual system of their extinct ancestors [21], but there are no studies that relate it with the locomotion of these extinct animals. We believe that head bobbing aids to enhance the visual system, but it also impacts the animal's biomechanics and the efficient use of energy by breaking the inertia and pushing the center of the mass forward to begin the first stride, consequently stabilizing the body during intermediary stages of movement. It is expected that non-avian theropods have also exhibited head bobbing during low speeds. We believe that the relationship between head bobbing motion and the existence of tails is an open research question that needs to be further analyzed.

In this context we are currently analyzing the consequences on kinetics and kinematics of the presence of a tail during bipedal locomotion of cursorial birds and theropods through virtual simulations. We will also carry out kinematic studies in a cursorial bird, whereby the biomechanical parameters that relate to head bobbing will be identified. Finally, we will also take direct energy records on bio-inspired physical models of a theropod to enable us to understand the mechanical principles that underlie movement and animal behavior [22-30], and to determine the mechanical advantage of the presence of a tail and head bobbing movement on bipedal theropod locomotion, thereby establishing adaptive advantages of exhibiting a tail and verify if it is possible to rethink the locomotion of primitive theropod dinosaurs using head bobbing during low speeds.

We expect that the results of this interdisciplinary research work will have an impact on the area of ecology and evolutionary biology, as well as on the modeling and construction of new bio-inspired robots. During the workshop the main aspects of the described research work will be presented.

REFERENCES

[1] Padian, K. and Chiappe L. M. "The origin and early evolution of birds." Biological Reviews 73: 1–42, 1998.

[2] Gauthier, J. and Gall, L. F. "New perspectives on the origin and early evolution of birds". New Haven: Peabody Museum of Natural History, Yale University. p .613, 2001.

[3] Norell, M.A. and Xu, X. "Feathered dinosaurs". Annual Review of Earth and Planetary Sciences 33: 277–299, 2005.

[4] Vargas, A. O. and Wagner, G. P. "*Frame-shifts of digit identity in bird evolution and Cyclopamine-treated wings"*. Evolution & Development 11(2): 163-189. 2009.

[5] Witmer, L. M. "Palaeontology: Feathered dinosaurs in a tangle". Nature 461: 601–602. 2009.

[6] Xu, X., You, H., Du, K. and Han, F. "An Archaeopteryx-like theropod from China and the origin of Avialae". Nature 475: 465-470. 2011.

[7] Novas, F. E., Salgado, L., Súarez, M. Angonín, F. Escurra, M. Chimiento, N. R., de la Cruz, R., Isasi, M. P., Vargas, A. O. and Rubilar-Rogers, D. "An enigmatic plant-eating theropod from the Late Jurassic period of Chile". *Nature* doi:10.1038/nature14307, 2015.

[8] Gatesy, S. M. "Functional evolution of the hindlimb and tail from basal theropods to birds". In: Thomason JJ, editor. Functional morphology in vertebrate paleontology. New York: Cambridge University Press. pp. 219–234, 1995.

[9] Carrano, M. T. and Biewener A. A. "Experimental alteration of limb posture in the chicken (Gallus gallus) and its bearing on the use of birds

as analogs for dinosaur locomotion". Journal of Morphology 240: 237–249. 1999.

[10] Paul, G. S. "The Scientific American book of dinosaurs." New York: St. Martin's Press. 424 p. 2000.

[11] Grossi, B., Iriarte-Díaz, J., Larach, O., Canals, M. and Vásquez, R. "Walking Like Dinosaurs: Chickens with Artificial Tails Provide Clues about Non-Avian Theropod Locomotion". PLoS ONE 9(2): e88458. doi:10.1371/journal.pone.0088458, 2014.

[12] Alexander, R. McN. "Estimates of speed of dinosaurs". Nature 261: 129-130. 1976.

[13] Alexander, R. McN. "*Dynamics of Dinosaurs and Other Extinct Giants",* Columbia Univ. Press, New York, 1989.

[14] Irby, G. V. "Paleoichnological evidence for running dinosaurs worldwide". Mus. N. Arizona Bull. 60, 109-112. 1999.

[15] Farlow, J., Gatesy, S. Holtz, T. Hutchinson, J. and Robinson, J. "Theropod Locomotion." Amer. Zool. 40: 640-663. 2000.

[16] Biewener, A. A. "Walking with tyrannosaurus". Nature 415: 971-973. 2002.

[17] Hutchinson, J. R. and Garcia, M. "Tyrannosaurus was not a fast runner". *Nature* 415, 1018–1021. 2002.

[18] West, G. B. and Brown, J. H. "The origin of allometric scaling laws in biology from genomes to ecosystems: towards a quantitative unifying theory of biological structure and organization". J exp. Biol. 208: 1575-1592. 2005.

[19] Hutchinson, J. R. and Gatesy, S. M. "Beyond the bones". Nature 440: 292-294. 2006.

[20] Friedman, M. B. "Visual control of head movements during avian locomotion". Nature 255: 67-69. 1975.

[21] Stevens, K. A. "Binocular vision in theropod dinosaurs". J. vert. Paleont. 26(2): 321-330. 2006.

[22] Full, R. J. and Tu, M. S. "Mechanics of a rapid running insect: two-, four. And six-legged locomotion." *J. Exp. Biol.* 156: 215-231. 1991.

[23] Full, R. J. and Koditschek, D. E. "Templates and anchors: neuromechanical hypotheses of legged locomotion on land". *J. Exp. Biol.* 202: 3325-3332. 1999.

[24] Dickinson, M. H., Farley, C. T., Full, R. J., Koehl, M. A. R., Kram, R and Lehman, S. "How Animals Move: An integrative view". Sience 288: 100-106. 2000.

[25] Autumn, K., Sitti, M., Liang, Y. A., Peattie, A. M., Hansen, W. R., Sponberg, S., Kenny, T. W., Fearing, R., Israelachvili, J. N. and Full, R. J. "Evidence for van der Waals adhesion in gecko setae." PNAS 99: 12252-12256. 2002.

[26] Pfeifer, R., Lungarella, M. and Lida, F. "Self-Organization, Embodiment, and Biologically Inspired Robotics." Science 314: 1088-1093. 2007.

[27] Hugel, V., Hackert, R. and Abourachid, A. "Kinematic modeling of bird locomotion from experimental data". IEEE trans. On Robotics 27(2) 185-200. 2011.

[28] Libby, T., Moore, T. Y., Chang-Siu, E. C., Li, D., Cohen, D. J. Jusufi, A. and Full, R. "Tail-assisted pitch control in lizard, robots and dinosaurs". Nature 481: 181-184. 2012.

[29] Werfel, J., Petersen, K. and Nagpal, R. "Designing Collective Behavior in a Termite-Inspired Robot Construction Team." Science. 754-758. [DOI:10.1126/science.1245842] 2014.

[30] A. Demir, M. M. Ankarali, J. P. Dyhr, K. A. Morgansen, T. L. Daniel and N. J. Cowan. "Inertial redirection of thrust forces for flight stabilization," in Proceedings of the International Conference on Climbing and Walking Robots, Baltimore, USA, July 2012.