High-speed X-ray cineradiography for imaging the mouthpart kinematics of living insects

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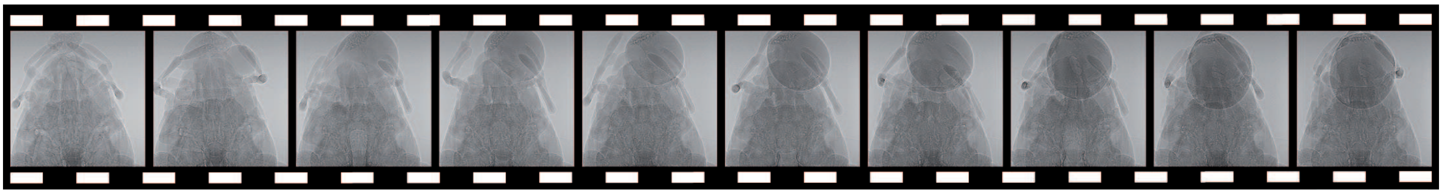
More than one hundred years ago, Lucien Bull showed, by means of his famous high-speed cinematographic movies of living species, the outstanding scientific value of time-resolved imaging. Synchrotron light sources such as ANKA allow the next step in the fast-imaging development: the use of hard X-rays [1].



Imaging with X-rays offers the chance to investigate more complex kinematics of feeding and locomotion structures of animals as it reveals internal information because of the penetrating nature of the radiation. Descriptive and experimental studies of the coordination and kinematics of the entire set of mouthparts during feeding in insects are scarce, because of the overlapping and often internal positions of structures of the oral apparatus. The introduction of high-speed X-ray cineradiography to insect morphology and biomechanics should provide researchers with the opportunity to address novel questions such as the control of complex rhythmic behaviour and the form and function of insect mouthparts in relation to their diet.

Insect mouthparts are highly integrated functional systems with tremendous diversity reflecting the vast variety of potential food sources. This makes them ideal model systems for studying comparative functional morphology and biomechanics. The action of the various mouthparts is rhythmic and highly coordinated. However, as they often overlap each other and take internal positions, the exact analysis of their kinematics has been challenging. Feeding systems provide great potential for the study of the mechanics and control of complex rhythmic behaviour, including potential biomimetic applications. These fields will greatly benefit from high-speed synchrotron micro-imaging in the Future 1.

High-resolution X-ray imaging by using synchrotron radiation has been extensively explored and applied since the 1990s. Indirect X-ray pixel detectors are frequently used to achieve high resolution. Here, the radiation is converted into visible light by a scintillating screen. The scintillator is coupled to a digital camera via visible light optics. In our case, we have used the (pre-filtered) white spectrum of ANKA's bending

References:

[1] *High-Speed X-ray Cineradiography for Analyzing Complex Kinematics in Living Insects ,O. Betz, A. Rack, C. Schmitt, A. Ershov, A. Dieterich, L. Körner, D. Haas, T. Baumbach, Synchrotron Radiation News, 21, 34-38 (2008).*

[2] *The micro-imaging station of the TopoTomo beamline at the ANKA synchrotron light source, A.Rack, T.Weitkamp, S.Bauer, P.Modregger, A.Cecilia, T.dos Santos Rolo, T.Rack, D.Haas, R.Simon, R.Heldele, M.Schulz, B.Mayzel, A.N.Danilewsky, T.Waterstradt, W.Diete, H.Riesemeier, B.R.Müller, T.Baumbach, Nuclear Instruments and Methods in Physics Research Section B 262 1978-1988 (2009).*

magnet port, the Topo Tomo beamline, to achieve a suitable high X-ray photon flux density. For digitial image acquisition, a CMOS camera is applied in order to attain the image acquisition speed of several hundred frames per second [1, 2]. In our experiments, we used individuals of the cockroach *Periplaneta americana* (Linné), see Figure 1. This species is well known for its worldwide distribution and association with human dwellings. Cockroaches (Blattaria) have biting and chewing mouthparts that represent the basic mouthpart condition in insects. Hence, they form adequate models for studying insect mouthpart function and coordination. On the dorsal side, the mouthparts are limited by the upper lip (labrum). The paired mandibles lie ventral to the labrum and are strongly sclerotized. They are rotated at their bases by strong closing and opening muscles. The mandibles not only are the major organs of food removal, but also function in reducing it to smaller pieces to be ingested. The paired maxillae each comprise of 3-4 movable segments plus a multi-segmented palp, providing a more complex grasping mechanism that is powered by up to 8 muscles that can rotate the base of the maxilla and adduct, flex, levate and depress various segments of this mechanism. Functionally, the maxillae assist the mandibles in food manipulation and processing. The ventral unpaired and multi-segmented labium forms the lower lip and completes the functional unit. In Figure 2, the changes of the opening and closing angles of the left and right mandible are shown over a specific time sequence. The movements of both the mandibles are well synchronized during the selected motion cycle. More detailed analyses should reveal any additional movement patterns of both the maxillae and the labium, running simultaneously to those of the mandibles. This will allow, for the first time, the construction and analysis of movement-time diagrams showing the synchronous movement pattern of the entire set of mouthparts of an insect.

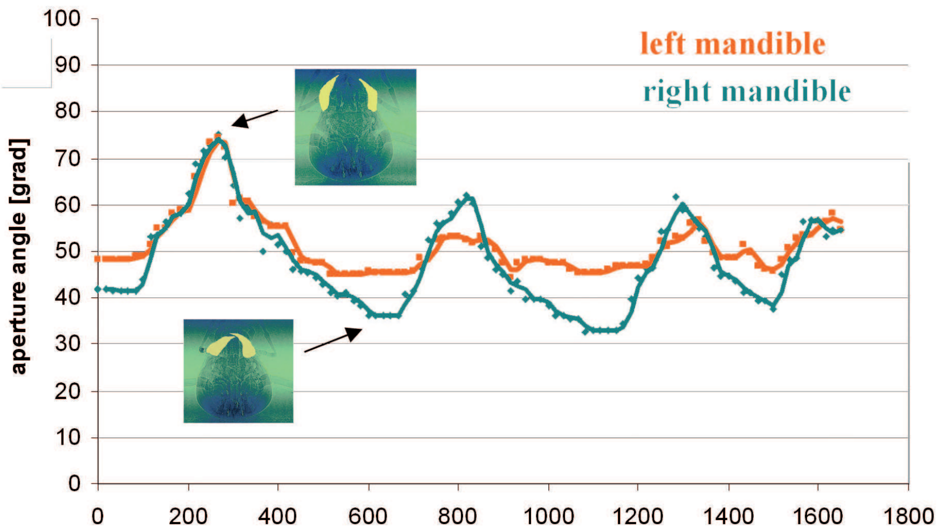


Figure 2: The diagram displays the change in the aperture angle ot the mandibles over the time. The mandibles shown in the pictures are highlighted in yellow.

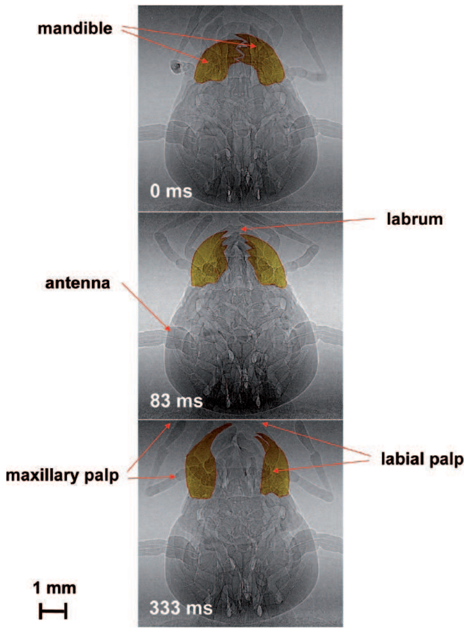


Figure 1: Sequence of three consecutive stages of mandible-movement. The opening of the completely closed mandibles (coloured mouth parts) takes about one-third of a second.

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