Exploring Dimensionality Reduction of Animal Flight Kinematics in an Interactive Virtual Reality Setting

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We present a case study in an expert evaluation of an interactive visualization system that provides a lower-dimensional decomposition of complex skeletal motion of a bat in flight. Scientists studying bat flight used the system to explore the linear combinations of components described by Proper Orthogonal Decomposition (POD) and uncovered and verified locomotion patterns.

We discovered that displaying experimentally captured kinematics data in an interactive three-dimensional setting provided an intuitive biological interpretation of biomechanical patterns. In particular, feedback from users who compared this environment with traditional two-dimensional graph methods showed that the advantage of seeing inherently 3D data in a virtual environment allowed them to better concentrate on data analyses. Subsequently, they were able to notice new motion patterns as well as differences and similarities in flight behavior at varying flight speeds.

Motivation Correctly characterizing the motion of a bat in flight has high potential in fostering discoveries in the biological evolution of flight and in constructing flight vehicles with increased maneuverability. However, bat flight motion data collected in wind tunnel experiments possesses a high degree of complexity and is difficult to understand using traditional kinematics analysis techniques such as graphs showing skeletal joint movement. To facilitate understanding of patterns in joint motion, it is important to present the data in terms of reduced complexity as well as give the users a means to interact with it intuitively. We used a well-known dimensionality reduction method, Proper Orthogonal Decomposition (POD) [Kirby 2001], to provide the users with a way to explore a lower number of motion components than the complete kinematics, while retaining all the dominant patterns in that motion.

User Evaluation The main goal of this study was to explore whether expert users – biologists and engineers – could use our system to gain a better understanding of bat flight. We were generally interested in their evaluation of possible biological meaning of POD decomposition and in the efficiency of using the user interface in order to perform their tasks. Our secondary goal was to gather feedback about design in order to further improve the interface. A qualitative study was conducted to help us understand whether the visualiation tool could help the users do their tasks.

Visualization Based on the feedback from our initial proof-of-concept prototype [Kostandov et al. 2006], we have provided additional analytical functionality and interactivity and more support for biological-domain tasks involving global, regional, and local examination.

The user interface consists of a keyboard and a mouse in a fish tank virtual reality environment [Ware et al. 1993]. Floating 3D menus are used to control visualization parameters, playback, timestepping, viewpoints, and navigation controls, as well as interactively explore the contributions of individual POD components (Fig. 1) and different combinations of components. We provide a number of options for model comparison, including side-by-side, overlaying, and a lateral combination of two models, as well as mesh, membrane, and skeleton visual representations of the motion capture data. Users can also trace any marker throughout the wingbeat cycle and display its position and trajectory on a grid plane.

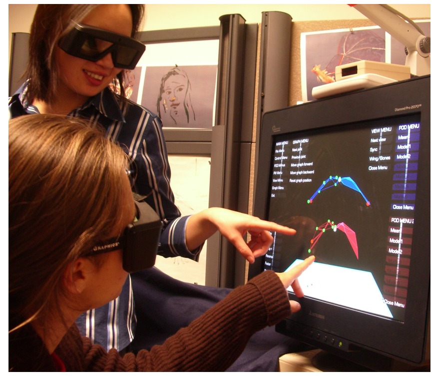

Figure 1: *Users comparing POD modes in a fish tank virtual reality environment. The datasets correspond to two different flight speeds.*

Results and Discussion According to the study, seeing virtual three-dimensional representations of 3D data in stereo provided our experts with intuitive and clear evidence of flight traits and features that they knew before and guided them towards discovering previously unknown ideas. Furthermore, the set of visualization features that was provided to them facilitated on-the-fly exploration of these ideas in novel ways. Users reported that this resulted in a deeper understanding of the issues they were interested in and often helped avoid problems encountered in traditional 2D analyses. An intuitive sense of timing provided by the environment also helped them notice patterns and relationships not seen or understood before.

Reducing cognitive load by providing an additional integrated view of data (for example, a two-dimensional projection of motion traces) proved to be an effective strategy; the users had this data always available and were able to fully focus on exploration tasks, quantifying and comparing features when necessary. In fact, several users considered this the most important feature of the visualization and reported that it helped significantly in generating insights. Consequently, when presented in the form of mini-views in a spreadsheet form [Chen et al. 2007], these trace projections further helped preserve task-related information for several datasets in parallel.

Interacting with the 3D visualization of lower-dimensional motion components also helped better understand their significance and functionality. As a result, the experts who participated in the study mentioned some interesting potential implications for motion analysis and modeling – characterizing the POD modes brings us another step closer to being able to build computational and physical bat models that will effectively encompass enough of the motion to be realistic from the point of view of biomechanics and aerodynamics.

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