Onboard video cameras and instruments to measure the flight behavior of birds

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Summary

We have recently developed several novel techniques to measure flight kinematic parameters on free-flying birds of prey using onboard wireless video cameras and inertial measurement systems [1]. Work to date has involved captive trained raptors including a Steppe Eagle (*Aquila nipalensis*), Peregrine falcon (*Falco peregrinus*) and Gyrfalcon (*Falco rusticolus*). We aim to describe mathematically the dynamics of the relationship between the position, speed, acceleration and orientation of the bird's body and the position and orientation of its control surfaces. Such models allow us to answer specific questions about the operation of the flight control system, and to make quantitative comparisons between the control systems of different species. Although developed specifically for measuring the behavior of birds in flight, aspects of this method will be applicable to studies of any large free-ranging animal requiring onboard logging of serial data or wireless transmission of video data.

Inertial Measurement Unit, GPS, logger and harness

The birds carry an inertial measurement unit (IMU) and global positioning system (GPS) unit, together with up to 4 wireless video cameras. The IMU/GPS unit (MTi-G, Xsens B.V., Enschede, Netherlands) outputs 3-axis velocity, orientation, angular velocity and acceleration at 100Hz, together with latitude, longitude, altitude, and static pressure. The IMU/GPS unit and the GPS antenna are mounted dorsally on the birds using a removable harness with Velcro fittings, such that the unit is mounted directly above the bird's centre of mass. A serial datalogger (Antilog RS232, Anticyclone Systems, Morden, Surrey, UK) is mounted ventrally on the harness, and logs data from the IMU/GPS unit to a 1GB SD card (Kingston Digital, Fountain Valley, CA, USA). Power is provided by lightweight rechargeable Lithium Polymer cells. The wires connecting the IMU/GPS unit and logger are routed through one of the harness straps, while the controls for the IMU/GPS and logger are mounted ventrally on the harness to allow easy access whilst the bird is on its handler's fist. The harness itself is worn in a similar way to a backpack, with dorsal and ventral strips of webbing onto which the IMU/GPS unit and logger are attached. Three of the harness straps incorporate weak links, rated to cause the harness to detach in the event of snagging.

Cameras, transmitters, antennae, receivers and recorders

Miniature CCD 'snake' cameras (Misumi, Chung-Ho City, Taiwan) connected to miniature 2.4GHz transmitters (Misumi, Chung-Ho City, Taiwan) used to record and transmit PAL video footage of the wings, head and tail. Up to 4 cameras can be used simultaneously. Additionally a wireless video camera with mirrored image splitter (Synceros Inc., Ithaca, NY, USA) can be used to give a stereo pair of images in a single frame, allowing three-dimensional reconstruction of the surface of the wings or tail. Power is provided by lightweight rechargeable Lithium Polymer cells. Signals are received by 1m-diameter parabolic antennae, connected to customised receiver units (634-RX, Low Power Radio Solutions, Witney, Oxfordshire, UK). The analogue signal is recorded digitally to mini-DV tapes by a Sony Handycam DCR-HC40E camcorder (Sony Corporation, Minato, Japan). Sequences are downloaded to a PC using iMovie (version 3.0.3, Apple Incorporated, California, USA) and deinterlaced to provide video at 50fps using JES Deinterlacer (Jan E. Schotsman, 2004). To date, we have achieved a transmission range of >1km in line of sight.

Synchronisation of the IMU/GPS output with the video

In addition to the serial output to the data logger, the IMU/GPS unit also outputs a 1Hz square wave. This is broadcast with the video data over the otherwise-unused audio channel and recorded with the video stream to mini-DV tape. This enables the video sequences to be synchronised with output of the IMU/GPS unit.

Loading and aerodynamics

In order to observe normal flight behavior from the birds, the weight and aerodynamic drag of the instrumentation and cameras are kept as low as possible. The added load is always <5% of the body weight of the bird, which is significantly less than the weight of prey items that these species would routinely carry in the wild. In any case, the size of the species in question limits the number of equipment items that can be carried, and at present only the 2.5kg Steppe Eagle is large enough to carry all of the equipment items. The instrumentation and cameras mounted on the back of the bird are streamlined by covering them with a lightweight nacelle, while the logger is built in flush to the harness.

Video analysis

All video analysis is done using custom-written software in Matlab (The Mathworks Inc., Natick, MA, USA). Manual identification of natural features and automatic pattern or shape recognition software is used to follow the movements of the tail. This enables changes in the pitch, roll and spread angles of the tail to be monitored throughout a flight. Summary variables are also obtained for the motions of the wing tips.

System identification

System identification [2] gives us a route into understanding the flight control system of the bird species studied, by analysing the dynamical relationship between the control inputs it makes and the response of its body. System identification has been used successfully for over half a century to determine experimentally the dynamics of what in control engineering is termed the 'plant' of a control system—typically the physical system being controlled, and in our case the animal's flight dynamics. System identification is here used to fit a dynamical model describing the response of the bird's body to observed control inputs made by the tail. The gross model structure is specified using theoretical insights from flight mechanics and aerodynamics. Finer details of model structure and estimates of its parameters are identified using maximum likelihood methods, minimization of prediction error, or other similar optimization procedures. The end result is a predictive model explaining how a horizontal triangular tail is used to control and stabilize the flight of a bird, without the aid of a vertical tail fin as used by most conventional aircraft.

References

1. Taylor, G.K., Bacic, M., Bomphrey, R.J., Carruthers, A.C., Gillies, J.A., Walker, S.M., and Thomas, A.L.R. (2008). New experimental approaches to the biology of flight control systems. *Journal of Experimental Biology* **211**, 258-266.
2. Klein, V. and Morelli, E. A. (2006). *Aircraft system identification: theory and practice*. AIAA, Reston VA.