Automatic phase detection of a bird wing in flight

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Abstract—An automated method for determining the phase transition points of a flying bird has been developed. Using a stereo camera setup with both views at different angles from the top were used to capture high speed video of a flying parrotlet. The video was then preprocessed to extract parameters from the left wing. The eccentricity of the region containing the wing was found to be the best classifier for finding the phase transitions. Furthermore possible boundary points between the upstroke and downstroke were compared between views and estimated based on the flapping frequency to achieve accurate phase transition points.

I. INTRODUCTION

Kinematics research of birds is currently limited in the way it relies heavily on manual processing of data. Although humans are remarkably good at identifying states in an image, recording rates of 1000 frames per second and the number of trials required for a prominent scientific investigation requires reconsidering the methods. Having computers process the data, will enable researchers to spend their efforts on analyzing and drawing conclusion from the parameters extracted. Typically data processing of bird flight data has been manually digitized through clicking marked points on the wings and subjectively determining when the phase transitions between upstroke and downstroke occur [2]. Not only will an automated approach save time for the researcher, but will also enable the use of larger data sets. The amount of manual processing work goes from scaling linearly with the number of data sets to becoming approximately constant. Thus improving the scientific significance of the research drastically through better statistics. It will also enable a faster turnaround between recording and analysis, allowing for more and faster iterations on the initial experimental setup in order to ensure that the data taken is of high quality.

This paper looks into a way of extracting the flapping phase from the images captured by stereo cameras with top views of a Pacific Parrotlet (Forpus coelestis) flying between two perches. A method was developed to distinguish and identify the boundaries of the three primary flapping phases of small birds: upstroke, downstroke and bounded flight. The upstroke is for this paper defined as the time the wing is moving up, the downstroke is the part of the stroke where the wing is going down and the bounded flight is a special case of an upstroke where the wings are held close to the body on the way up for more than one flapping period before normal flight is resumed [4]. The distinction between these phases is important for matching important flight parameters to the right part of the stroke, as the phases all have distinctly different effects on the flight.

The paper begins by describing the setup used to capture the videos. Then it goes on to describe the method used in detail and some of the steps taken to develop it. Lastly the performance is analyzed and an argument is made as to why the method works and what it relies on. Throughout the development, methods involving training were not considered due to the act of having to label training sets. The method outlined in this paper can later be used for labeling data sets for training of a model which is less dependent on consecutive flapping cycles. The method outlined in this paper relies purely on the data recorded for the one run that is analyzed and this makes the method’s performance independent of data set size, which is favorable.

II. EXPERIMENTAL SETUP

The experiments were conducted on a long table with two perches located between 1m and 1.5m apart. This was enough to have the take off and landing strokes occur before and after the bird was in the frame. Aurora, a Pacific Parrotlet (Forpus coelestis) was trained to fly between the perches on cue, using positive reinforcement training. The middle of the flight path was illuminated by two ARRI 650 studio lights and filmed with two Phantom Miro M310 with Nikon f/2.8, 24-85 mm zoom lenses. The cameras were located with one camera behind the bird at about 30 deg angle to the horizontal and another camera behind at about 60 deg, giving them a 30 deg stereo angle which should be enough to track the wing in 3D during further data processing (Fig. 1).

The images were taken at 1000 frames per second with an exposure time of 200ms to reduce motion blur. A total of 20 flights were recorded and only the part from right before the bird entered the first camera to the point where the bird got out of the illuminated area were saved. Out of these 20 flights, 12 were noted as having at least two consecutive flapping cycles, where a flapping cycle is defined as a full upstroke followed by a full downstroke. Before each flight the bird was carried over to the perch closest to the cameras on a portable perch. The bird was trained to fly whenever the far perch was pointed to with a finger. After the flight, the cameras were post-triggered and the bird was given a millet seed as reward. A couple of flights were not recorded due to the bird not flying directly to the far perch and thus flying at an angle to the video frames. This could be accounted for, but to keep the data set consistent and to preserve storage space it was decided that only direct flight were stored.

III. METHODS

In order to extract parameters to use for determining the boundaries between stroke cycles, the outline of the wings
were first extracted from the frame range with the whole bird in view. These were then scaled to account for differences in the distance away from the cameras. This was done separately for each camera and the parameters extracted were combined in the end to ensure consistency and account for variances in flight behavior.

The first step in identifying the wing was to binarize the image by keeping only values 5 times higher than the median value and noise was rejected by only keeping regions with more than 15000 pixels. The resulting region was first used to identify the frames in which the whole region occurred within the frame horizontally and only these frames were considered for phase identification. Furthermore we needed to identify a bounding box around the left wing. This was done by finding the first row from the top of the region which had more than 90% of the number of pixels compared to the maximum width of the whole region. The body of the bird tends to be at least 10% wider than any wing portion, thus this effectively only keeps the wing. To avoid sudden jumps between frames, a median filter looking at the last 7 frames was used to pick a suitable row to define as the start of the wing. Considering only the region above the chosen row, the first and last columns which contained more than 5 pixels were defined as the bounds on the width of the region. Through looking at the data collected it was found that the wing never reached more than 400 pixels wide, so the bounding box was chosen to be 400 pixels above the aforementioned bottom row. This entire box in both the binary image and the original image was then scaled onto a 400x400 image.

Having sufficiently extracted only the wing, the following parameters were considered for identifying the boundaries of the stroke phases:

- Coefficient with the first eigenpicture [3].

Most of these did really well in determining the middle of the downstroke, as this is the part where the wing is the widest and has the largest area, but when it comes to determining the boundaries of the stroke phases it gets a lot harder. The first eigenpicture is the classifier with the most variance within the flight, thus it is reasonable to believe that it would be helpful in determining the phase. However, it turns out that the first eigenpicture is almost the same as using wing width. As we can see from Fig. 2A, that the wing has a slight dip in width around the start of the downstroke, but it is very slight and not consistent. Also there is a large drop in width at the end of the downstroke, but there are few defining characteristics to exactly pinpoint the location of the stroke reversal. This makes it and consequently the eigen coefficient a poor parameter to use in order to define the boundaries of the up- and down-strokes. We can however observe that the eigencoefficients have a quite clean periodicity to them, and thus taking the autocorrelation gave a good way of determining the flapping frequency of the bird. Fig. 2B shows the autocorrelation of the first eigen coefficient, and we can observe that the flapping period of the bird is 40 ms, and thus the flapping frequency is 25 Hz.

It turned out that peaks in the eccentricity of an ellipse
with second moment equal to the wing area was the most reliable and consistent parameter in classifying the stroke phase boundaries. Firstly all peaks above a threshold of 0.95 are identified and only the peaks which are within 5 pixels of each other on both cameras are kept. Using these points all the peaks which occur in one camera view and are one period away from the initially recovered peaks are brought back. Then the peaks are checked for consistency to fill gaps where we would expect peaks based of points in the flapping cycle before and after. Lastly regions are labeled as upstroke, downstroke or bounding depending on if they are less than half a period, longer than half a period but less than a full period and longer than a period respectively. Having identified all the phase regions, it was necessary to shift the peaks for the start of the upstroke as these peaks turned out to be quite flat and the stroke reversal happened at the beginning of the peak. These boundaries relocated at the first frame which had 99% of the eccentricity of the peak. This proved to reliably and consistently identify the stroke reversal at the correct location.

IV. RESULTS AND ANALYSIS

A total of 20 data sets were recorded, and 12 of these were marked as good by containing at least two full consecutive flapping cycles. The method was able to correctly identify all the boundaries to within 3 frames of manually determined boundaries in 11 flights. This corresponds to a 92% recognition rate and the marked regions are shown in Fig. 3 together with the manually determined boundaries. This result was quite remarkable considering that one would not expect the eccentricity to yield such consistent results, but looking at it in more detail at what happens right around the stroke reversal some more insight may be gained.

Eccentricity is a parameter with values between 0 and 1 and is a measure of how circle or line like an ellipse is. The eccentricity used is the eccentricity of an ellipse with the same second moment as the wing template, and an eccentricity of 1 would be a line segment and an eccentricity of 0 is a circle [1]. Fig 4 shows in detail how the eccentricity of a fitted ellipse
indeed should have a peak at the stroke reversal. At the start of the downstroke the bird goes from having its wrist joint tucked in towards the body, to pushing it out. This motion makes the first primary feathers sweep around before they also start moving outwards, creating a very slender ellipse just as the feathers are reversing. The effect produces a maximum in the eccentricity exactly at the point of stroke reversal. At the beginning of the upstroke a similar phenomenon can be observed as the primaries are swept outwards, but it is not as clear due to occlusions by the body and the peak occurs slightly late since the first part of the reversal is completely occluded by the forearm of the wing.

V. Conclusion

Identifying the boundaries between downstroke and upstroke is by no means as trivial as finding the middle of the downstroke, but by looking the eccentricity of the region defined by a wing, a maximum was consistently observed at the start of the downstroke. Similarly, but not as strong there was a peak slightly before the start of the upstroke making it possible to also estimate accurately the onset of the upstroke. Furthermore by having the redundancy of two cameras and logic to make corrections based on the flapping period made this method perform remarkably well.

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