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Feasibility of vibration energy harvesting powered wireless tracking of falcons in flight

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Abstract. The use of wireless tagging of birds has been widely used for monitoring or tracking purposes. This include over 10 thousand wireless tracking devices currently used by the UK falconers alone. However, due to the concern of not burdening the birds with a heavy battery, the existing lightweight telemetry tracking systems can only last for days, if not hours. Falcons can have top flight speeds in excess of a hundred miles an hour, which makes it a near impossible task to track a missing falcon after the battery has been depleted. This paper investigates the feasibility of incorporating a piezoelectric vibration energy harvesting system to act as a secondary power source for the wireless tracking of falcons. The ultimate aim is to both extend the primary battery life and enable periodic burst transmissions of telemetry after the depletion of the primary battery. The presented tracking and harvesting system is lightweight and has been field trialled on a gyrfalcon at the Chester Cathedral Falconry.

1. Introduction

Wireless tagging of avian species has existed for decades, including the monitoring of birds during migration and the tracking of birds of prey by sanctuaries and falconries. Falcons can have top flight speeds in excess of a hundred miles an hour, making it extremely difficult to track outside the visual range, without the assistance of a telemetry system. There are over 25 thousand falconers in the UK alone and an estimated 10 thousand wireless tracking devices are used on birds of prey in the UK to-date [1]. This typically included radio-transmitters that have limited transmission range, but conservationists have increasingly moved towards the more accurate Global Positioning System (GPS) for telemetry [2].

However, due to the critical need to minimise the overall weight of the tag in order to minimise burden on the birds, the battery life of the wireless telemetry system is very limited. Despite the more accurate telemetry capabilities, GPS require more power budget than radio transmitters. Furthermore, this technological challenge has resulted in the limited weight budget of the wireless tracker for birds (typically in the order of few grams to few tens of grams) been overwhelmingly occupied by the battery, with the active wireless device only able to occupy a small fraction of the overall device weight [3].

In the meantime, energy harvesting has been an emerging technology in recent years that has been demonstrated as a means to recover ambient energy to replenish the batteries for microelectronics [4]. The use of solar and vibration energy harvesting methods to power wireless tracking has been previously investigated in the literature [5]. However, the mean concern on minimising the parasitic effects and burden on birds still linger. Solar cells require large surface area and is only suitable under direct solar irradiation. On the other hand, the use of backpack-like mechanisms to recover vibration energy [3] can be a source of parasitic burden for the body and the wings that cause distress for the birds.

This paper reports a new approach to harvest the vibration energy of birds, with a specific focus on birds of prey due to collaboration and access to field trails with the Chester Cathedral Falconry [6]. The proposed system employs a lightweight piezoelectric cantilever-based mechanism attached to the tail feather of a falcon. In an interview with the Chester Cathedral Falconry, the falconers provided an end-user design specification of achieving an add-on system weighing less than 10 grams to their existing wireless tracker.

2. Method

The Chester Cathedral Falconry used off-the-shelf radio transmitters with wire antenna on their falcons. These tracking devices weighed just under 10 grams and were clipped into a tail feather harness using a spring clip mechanism. The lightweight fixture on the tail feather resulted in minimal stress for the birds. The battery life of the radio transmitter lasts 3 weeks and the range of transmission does not extend far beyond the visual range ($\sim$ 100 m). While the more accurate and range-independent GPS tracking devices were available for the falconry too, the battery life does not last more than 1 day.

In order to extend and complement the battery powered trackers, a piezoelectric vibration energy harvesting (VEH) system was integrated. A key objective of the study was to validate the feasibility of applying piezoelectric VEH to the tail feather of falcons. MIDE's PPA-1022 piezoelectric beam was employed, which had a 0.18 mm thick PZT-5H layer. The FR4 encapsulated beam was 53.0 mm in length, 10.3 mm in width, 0.7 mm in thickness and weighed 0.8 grams. The beam was attached to the casing of the radio transmitter in a cantilever-based arrangement. However, since the radio transmitter itself is only clipped onto the tail feather harness, the PZT cantilever beam is not strongly anchored to a fixed plane.

Design of the experimental setup in a lab environment is shown in figure 1, where the harvester is clipped into the tail feather harness and is fixed on a mount that interfaces with a mechanical shaker for vibration testing.

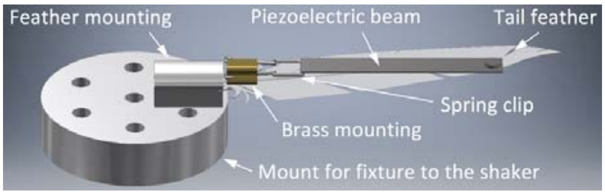

Figure 1. Design of the proposed system for laboratory experimentation on a shaker table. The harvester recovers vibration of the tail feather and radio antenna (not shown here) primarily through cantilever beam bending oscillation.

An image of the transducer is shown in figure 2 and the assembled setup on a mechanical shaker is shown in figure 3. The PZT beam is able to respond to the base point excitation as well as the oscillation of the tail feather and the radio antenna. A full bridge rectifier circuit using die level Schottky diodes were assembled on a small circuit board was used to interface the PZT element and an AVX super-capacitor (measured at 5 μF) as illustrated in figure 4. The overall assembled system that has been used during the field trial is shown in figure 5.

A specific gyrfalcon by the name of Buck was chosen for the field trials. Video image analysis of the falcon's flight estimated a tail feather motion of approximately 4 Hz to 6 Hz with an average acceleration attaining $\sim$ 1 g near the tail feather harness. The frequency of the harvester beam can be tuned to $\sim$ 5 Hz by adding 3 grams of end mass.

Figure 2. PZT beam.

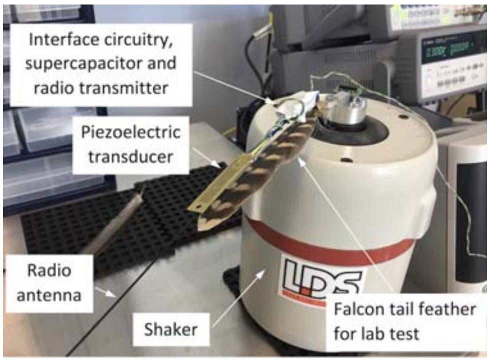

Figure 3. Experimental apparatus setup on a mechanical shaker. The system can be securely clipped onto the tail feather harness. Representative vibration tests were carried out.

Figure 4. Rectification and storage circuitry.

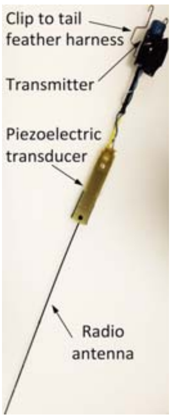

Figure 5. Assembled tracking and harvester system.

3. Experimental results

The frequency responses of the harvester with and without end mass, when subjected to various levels of base-point input acceleration, are shown in figures 6 and 7. An average power in excess of 0.7 mW was observed at 0.5 g acceleration at 5 Hz. However, real tail falcon vibration during flight is unlikely to be purely sinusoidal and continuous, and the frequency is likely to be varying in nature. Therefore, the device is not expected to operate in steady resonance.

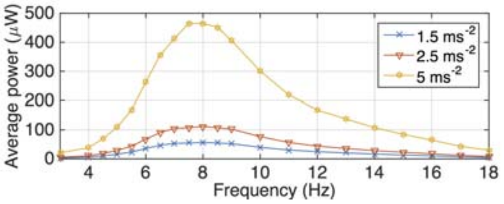

Figure 6. Frequency domain power output of the PZT harvester with no end mass.

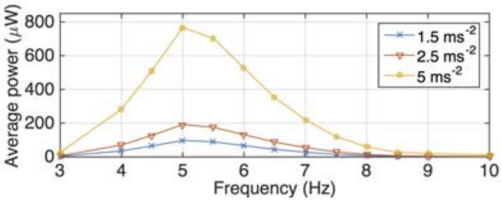

Figure 7. Frequency domain power output of the PZT harvester with 3 grams end mass.

4. Field trial

The assembled prototype device seen in figure 5 was clipped onto the existing falcon tail harness as shown in figure 8. The overall weight of the add on system (including the harvester, end mass, circuit, storage capacitor and fixture) was about 5 grams. Figure 9 show the gyrfalcon in flight with the prototype device.

A number of tests were carried out across various dates. Voltage across the super-capacitor was measured before and after the falcon flight show on the day. Due to logistic limitations, only 1 measurement was possible per show. Table 1 summarises the measurements taken from 3 different field trials. A parasitic leakage of about 0.8 μW from the circuitry was measured. This further disadvantaged the field trial measurement experiment, as the falcon was on land during most part of the show and flight time only lasted approximately 5 minutes.

The maximum average power recovered was $\sim$3 μW. This deviation from the laboratory testing is due to the additional continuous parasitic leakage from the circuitry when the bird is

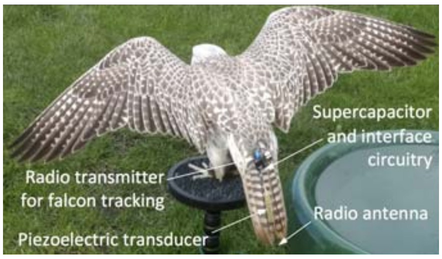

Figure 8. Radio tracking system and piezoelectric vibration harvester on a gyrfalcon.

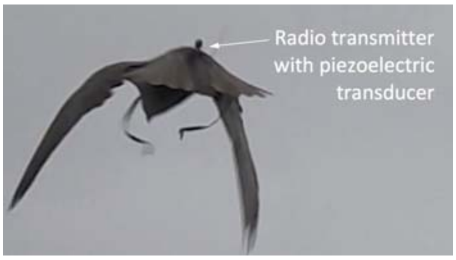

Figure 9. Gyrfalcon in flight with the radio tracking system and piezoelectric harvester.

Table 1. Field trial results of recovered energy into a 5 μF supercapacitor during 3 different tests on a gyrfalcon in flight. All tests lasted 5 minutes. The circuit has an average parasitic leakage of 0.79 μW. The average generated power presented here compensates for this loss.

	Start voltage (V)	End voltage (V)	Energy stored (mJ)	Average generated power (μW)
Test 1	0.005	0.057	0.008	0.82
Test 2	1.223	1.302	0.499	2.45
Test 3	1.230	1.344	0.734	3.23

not in flight. Nonetheless, despite the significant parasitic losses and non-continuous excitation conditions, the field trials revealed positive results in terms of net energy gain from the harvesting of tail feather motion during flight.

Conclusion and future work

A prototype device that incorporates piezoelectric VEH onto a radio tracking device was developed. While a number of challenges still persist, such as parasitic losses and optimal frequency tuning, the field trails validated the feasibility of recovering energy from falcon tail feathers during flight. The result holds promise to extend the battery life of tracking devices for birds, as well as the VEH system being used as a back up power source for wireless transmitters long after the primary battery has been depleted. Future work involves further dynamic analysis of bird tail motion in order to better understand the vibration spectrum for design optimisation.

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