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SHORT COMMUNICATION

A NEW TECHNIQUE TO MONITOR THE FLIGHT PATHS OF BIRDS

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The study of the mechanisms which govern bird orientation and navigation is severely hindered by the difficulty of reconstructing the route taken by the bird. Several methods have been used to study bird flights: direct observation using binoculars; following the bird by aeroplane or helicopter (Griffin, 1943; Hitchcock, 1952; Fiaschi, Baldaccini, Ioalè & Papi, 1981); using a transmitter carried by the bird (Michener & Walcott, 1966; Schmidt-Koenig & Walcott, 1978); and location of the bird using radar techniques (Eastwood, 1967; Papi & Pardi, 1978). All these techniques require that the bird and the monitoring equipment always be within optical or electromagnetic 'visibility'.

In this paper we propose a technique whereby the direction in which the bird is heading during flight is detected and stored, at pre-fixed time intervals, by a device attached to its back. When the bird is retrieved, the stored data, when processed (assuming adequate hypotheses) allow a reasonable reconstruction of the route followed.

The proposed device measures the angle θ between the horizontal components of the earth's magnetic field and of an axis of the device, coincident with the main axis of the bird's body. The device consists of a traditional compass equipped with a new transducer to convert the angular values into electrical resistance values which entrain the frequency of an oscillator.

Obviously, the knowledge of function $\theta(t)$, where t is the sampling time, is not sufficient to characterize unequivocally the route followed. It does, however, constitute a useful point from which the flight path can be traced by an iterative and interactive process.

Solid-state compasses were not taken into consideration because an acceptable sensitivity is associated with large weight and size.

Key words: flight path recording, heading sensor, *Aves*, homing pigeon.

The route angle transducer consists (see Fig. 1) of a pair of magnetic needles fixed to a plastic disc, symmetrically arranged with respect to the centre; the disc rotates around its central axis. The disc is opaque except for a transparent circular zone, whose width varies linearly along the circumference. In correspondence with the median of the transparent band and on opposite faces of the disc, a LED–photoresistor couple is located. As the bird's heading varies, the position of the disc with respect to the LED–photoresistor couple also varies, causing a variation in the resistance R of the photoresistor. The variation of R modifies the frequency of an oscillator (see Fig. 2) so that a linear relationship between the angle and the oscillator frequency, N, finally results.

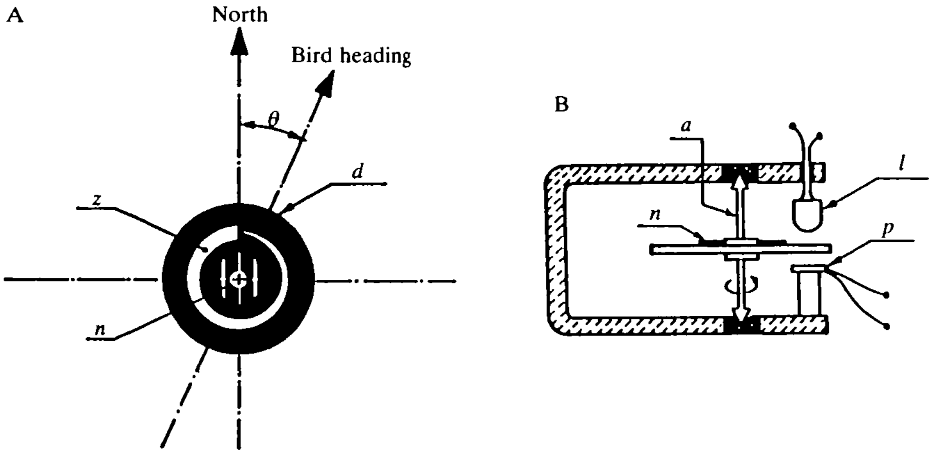

Fig. 1. Schematic view of the compass. (A) Top view of the disc; (B) vertical section of the compass; *a*, axis; *d*, disc; *l*, LED; *n*, needle; *p*, photoresistor; *z*, transparent zone.

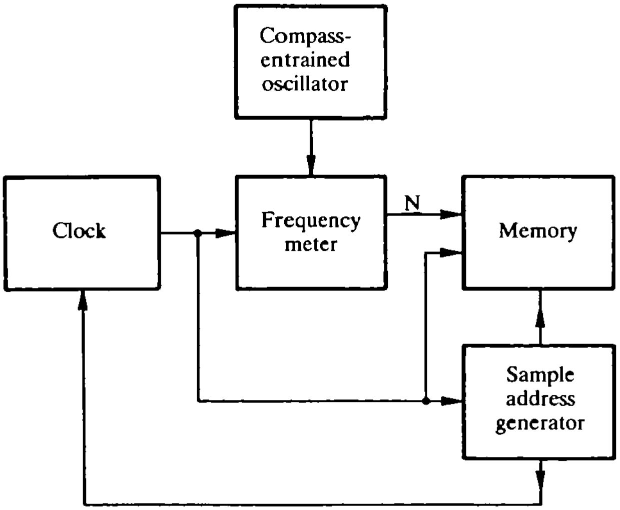

Fig. 2. Block diagram of the device.

At regular time intervals, given by the clock oscillator, the function $N(\theta)$ is measured and its value stored in a digital memory; the address generator, advanced by the clock, addresses the memory and stops the clock oscillator when the memory is filled.

The device was constructed using five commercial chips with a dual in-line plastic package, including a 2 kbyte memory. Such a capacity permits approximately 10 h of recording at a sample period of 20 s.

The prototype (see Fig. 3) measured about 95×28×15 mm and weighed 23 g, plus 7 g for four series-connected mercury batteries (1·4 V, 70 mAh).

The program for data processing and restitution first transforms the data $[N(\theta)]$ into degrees with respect to North. For this purpose, the operator must supply the following data.

(1) Position of the 'dead' angle. This position is defined as the bearing towards which the device must be headed to get the LED illuminating the discontinuity of the transparent zone of the disc.

(2) Three values of N measured by the device when it is headed in certain specific directions; these values are used for calibration and interpolation purposes.

(3) The position of the device on the bird; that is, whether the compass is positioned near the bird's head or near its tail.

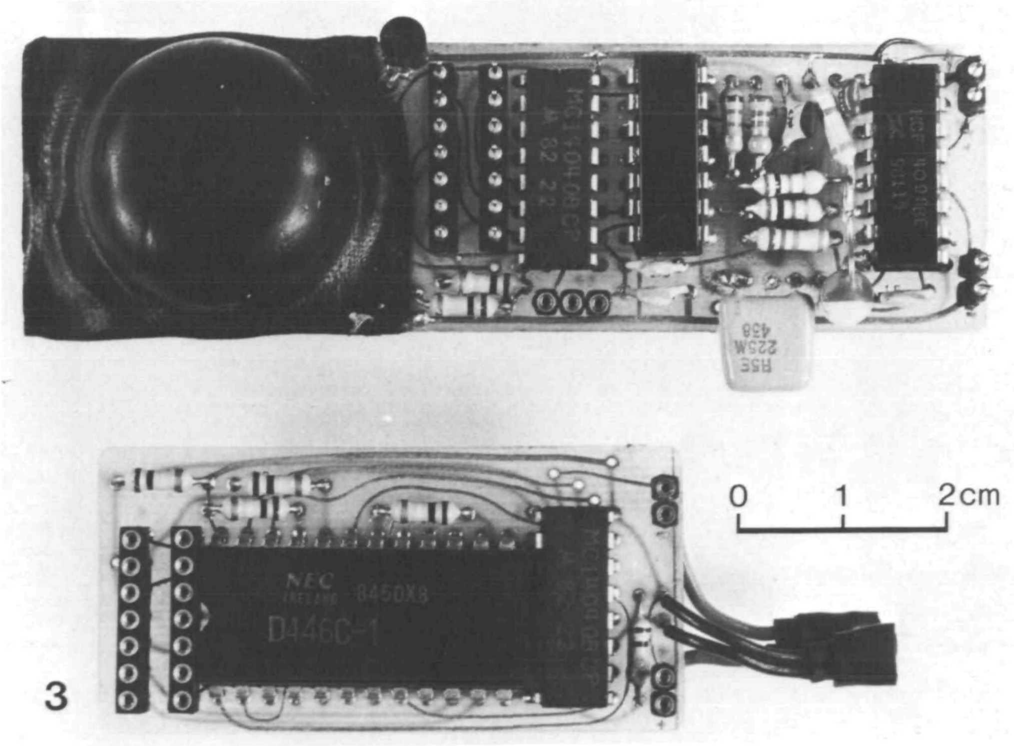

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Fig. 3. View of the device with batteries.

To visualize the flight track it is also necessary to define: (1) the initial coordinates of the graph on the screen; (2) the orientation of the graph on the screen (this facility allows us, for example, to account for magnetic declination); (3) a subdivision of the graph into one or more legs; (4) for each leg, wind speed and direction, and assumed speed of the pigeon; and (5) the scale factor of the graph and the device sample frequency.

From all these data, the coordinates of the points which will be successively passed over by the pigeon, from the beginning of its flight, can be calculated, assuming the speed defined above in point 4, corrected by the wind velocity of the corresponding leg. A new display can be obtained by redefining the sections with the relative wind and pigeon speed, the part of the graph to be displayed, the scale factor and the point at which the graph begins.

Five prototypes were produced and tested over a number of homing routes to the loft at Arnino (near Pisa) from the following release sites: Viareggio (26 km North), Vada (36 km SSE), Calambrone (6·5 km South).

Analysis of the direction data has shown a noise superimposed on the signal and due to oscillations in the mobile part of the compass. As the average value of the noise was null, its effect on the overall direction of the flight paths was negligible so that no recorded value was rejected.

The data used for reconstructing the flight path were processed by first hypothesizing a constant pigeon speed with respect to the ground, and then using the other information available, such as the departure and arrival times and sites.

All the analyses made using this model have shown an overall difference between the global direction of the reconstructed flight path and the actual one (the direction of the line from the release to the arrival site) of many degrees. These deviations have been found to be a consequence of the wind drift.

The tracks can, however, be corrected using a method based on the triangle of velocities. This model assumes a constant speed for the bird with respect to the air with a direction corresponding to the vectorial difference between the bird's velocity with respect to the ground and that of the wind. Wind speed and direction are measured at three or four points of the flight area.

All the flight paths reconstructed according to this model have given small differences between the reconstructed course and the actual one.

In September 1986, two groups of pigeons (*A*,*B*) were released at Vada (see Fig. 4). Only two pigeons in each group carried route recorders; the sampling frequencies were about 20 samples min^{-1}. Group *A* was released first and group *B* was released 13 min later. Wind direction and speed were measured immediately after release of the second group, at the places indicated in Fig. 4. The paths *a*1, *a*2 and *b*1, *b*2 were obtained without taking into account the wind's influence. The corresponding paths *A*1, *A*2 and *B*1, *B*2 were obtained by taking into account the wind, using the values reported on the left-hand side of the figures. For each bird, the speed with respect to the air was chosen to minimize the distance between the actual arrival point and the reconstructed one. The speed values to be assumed were in the range 50–65 km h^{-1}. Different values were required to account for the

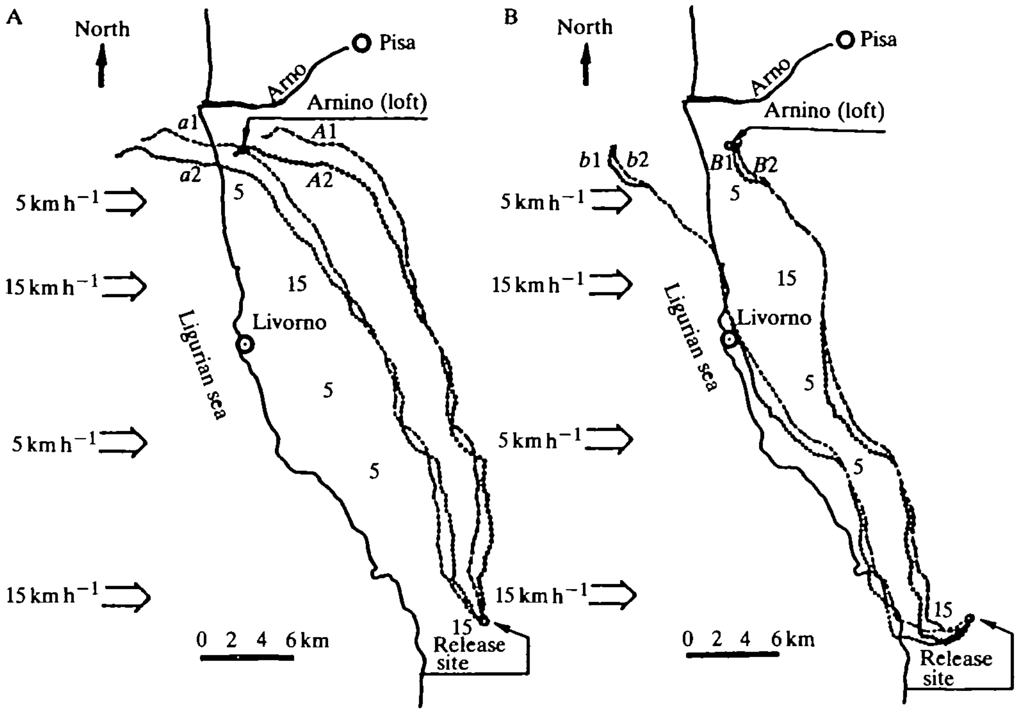

Fig. 4. (A) Homing routes of two pigeons that were released, and homed, together. The tracks are drawn without (*a*1, *a*2) and with (*A*1, *A*2) correction for wind influence. On the left, estimated values of wind direction and speed are given. The differences between the final parts of the two reconstructed tracks are mainly due to the influence of the dead angles of the compasses (West for *A*1 and South for *A*2). Note that, when the tracks overlap, only one has been drawn. Small loops present in the initial part of the flight are not shown due to the scale of the graphs. (B) Homing routes of two further pigeons released at the same site as in A. The dead angles of the compasses were East for *B*1 and South for *B*2. Other explanations as for case A.

different noise amplitudes of the compasses and for incorrect samples taken when heading towards the dead angle. The dead angles were not the same for the four devices. The birds of each group were released together, and arrived together. Homing time was 54 min for Group *A* and 58 min for Group *B*.

The prototypes were constructed by C. A. Giorgi of IEI; the birds were trained by P. Ioalè of the Dipartimento di Scienze del Comportamento Animale of Pisa University.

REFERENCES

EASTWOOD, E. (1967). *Radar Ornithology*. London: Methuen.

FIASCHI, V., BALDACCINI, N. E., IOALÈ, P. & PAPI, F. (1981). Helicopter observations of homing in pigeons with biased orientation because of deflected winds at the home loft. *Monitore zool. ital.* 15, 139–153.

GRIFFIN, D. R. (1943). Homing experiments with Herring Gulls and Common Terns. *Bird-Binding* **14**, 7–33.

HITCHCOCK, H. B. (1952). Airplane observations of homing pigeons. *Proc. Am. Phil. Soc.* **96**, 270–289.

MICHENER, M. C. & WALCOTT, C. (1966). Navigation of single homing pigeons: airplane observations by radio tracking. *Science* **154**, 410–413.

PAPI, F. & PARDI, L. (1968). The initial orientation of homing pigeons observed by radar. *Monitore zool. ital.* **2**, 87–93.

SCHMIDT-KOENIG, K. & WALCOTT, C. (1978). Tracks of pigeons homing with frosted lenses. *Anim. Behav.* **26**, 480–486.