The GPS Flight Recorder for Homing Pigeons Works:
Design and First Results

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Abstract:

This paper describes a first version of the GPS flight recorder for homing pigeons. The GPS recorder consists of a hybrid GPS board, a patch antenna 19*19 mm, a 3 V Lithium battery as power supply, a DC-DC converter, a logging facility and an additional microprocessor. It has a weight of 33g. Prototypes were tested and worked reliably with a sampling rate of 1/sec and with an operation time of about 3 h. In first tests on homing pigeons 9 flight paths were recorded, showing details like loops flown immediately after the release, complete routes over 30 km including detours, rest periods and speed.

Introduction:

For several years we have tried to develop a GPS flight recorder, specifically designed for homing pigeons in order to accurately measure flying positions and record their flight paths [2].

Homing pigeons are able to home from places where they have never been before and the mechanism of navigation is not yet completely understood [6,9]. For this reason, it may be helpful to record the flight paths of homing pigeons, in order to correlate them with the topografical structure of the area and other factors that are suspected to be involved in their navigation.

The technical reason for developing a new type of flight recorder is that the other methods used so far for measuring the flight paths of birds like ARGOS, conventional radio tracking, aircrafts and a magnetic direction recording device have major disadvantages. These are either small range, low resolution in time and space and lack of accuracy or a lot of effort to carry out measurements or high operation costs.

For a detailed description of navigation technologies which can be used for measuring and recording flight paths, their advantages and disadvantages see our former publications [3,4].

We are here describing the first version of the GPS flight recorder. Giving examples of the flight paths of homing pigeons from a site 30 km from the home loft, we demonstrate its effectiveness.

Requirements

There are several challenges to measuring the flight paths of pigeons. The birds are rather small, 300-500g, and should not be burdened with more than 10% of their body weight. Orientation experiments are performed within a medium range of 10-200 km. The pigeons move fast with an average speed of 70 km/h. They come home within 0.3 - 24 h after release (= take off). The advantage of this short duration of flight is that the flight recorder needs to work only for several hours, the disadvantage is that a high sampling rate is necessary in order to get a good resolution of the flight path. For tracking experiments a big advantage of pigeons in contrast to other animals is that they return to their home loft on their own and can easily be recaptured. They need not be trapped outdoors, so that the data can be logged and need not be retransmitted. Pigeons' backs have a free access to the sky as long as they fly. Thus satellites can be received with no obstruction.

These conditions lead us to set up the following major requirements for a flight recorder:

- Recording of position and speed with a good accuracy (100-300 m)
- Small dimensions (70*40*30 mm)
- Low weight: about 30 g (with antenna and power supply)
- Sampling rate 5 sec - 5 min
- Operation time: 3 - 12 h

We decided that GPS, Global Positioning System, [3] is the best technical system to fit these requirements.

Advantages and disadvantages of GPS

GPS offers:
- high accuracy of position
- possible sampling rate of once per second
- no transmissions in flight
- worldwide availability

Major disadvantages of GPS for this application are:
- size and weight of components
- power consumption
- high cost of devices
- animals have to be recaptured to retrieve the data, the GPS recorder and all the data may be lost, if the animal does not return to the loft
- residual magnetic field

Design of the GPS recorder:

The GPS recorder (Fig. 1) measures the position of the pigeon during its flight and records these positions in internal memory. At the end of the pigeon's flight the position data are downloaded to a computer. Then the flight paths or parts of it can be calculated or displayed on a map.
Data protection in case of power failure is achieved, because the positions are stored on a flash RAM. Data can be downloaded as NMEA (standard defined by the National Marine Electronics Association, USA), in a company owned format or as ASCII text. NMEA data are converted by a Visual basic program to allow processing by standard PC software.

The GPS recorder consists of a GPS antenna, a GPS receiver board, a datalogger, a power supply, a DC-DC converter, a connector and a display of status. It has a weight of 33g and a physical size of 8.5 * 4 * 1.5 cm. The GPS recorder has a sampling rate of 1/sec and operates for approximately 3 hours.

Figure 1: GPS recorder stand alone (left) and on a pigeon (right)

Components

Antenna: Passive patch antenna with a size of 19*19 mm
GPS board: 1 hybrid board with a size of 30*30 mm -weight: 6.2 g
measuring position with the standard positioning service SPS.
Datalogger: A logging facility storing the GPS positions directly on the receiver board, external logging is also possible
Power supply: A primary lithium battery of 11 g.
DC DC converter: The voltage of the battery is adapted to the voltage of the GPS receiver
Connector: for the PC interface
Indicator: The internal status of the device is indicated.
External microprocessor. M. Riechmann and the fourth author wrote a program for the microprocessor to control the mode of the device. In the measuring mode it correctly starts up the GPS receiver and initializes it with the desired parameters.

Hardware interface between the GPS flight recorder and the PC:

built by H.J. Hamann and M. Riechmann allowing transfer of the data between PC and GPS recorder.

Casing In this first version the GPS recorder was packed in thin plastic foil and attached to a the pigeon with velcro on a harness (after a design by Kenward *et al.* [5]). The harness consists of an epoxid back plate with a strip of velcro on it, an epoxid breast plate and Teflon ribbon. It has a weight of 7 g.

Software:

1. Software to download the data from the GPS recorder and to watch the GPS receiver sending messages while operating.
2. Software to convert NMEA to other formats. It was written by the first and second author.
3. Software to plot GPS data. The programs: Fugawi, Sigma plot, Top50 Hessen are available commercially.

Experiments:

Training of the pigeons:

We used adult, experienced pigeons to test the GPS recorder. 10 pigeons were trained for 3 months carrying the harness and increasing weights. They were released from increasing distances and different directions to get used both to carrying the harness and the additional weight.

Test flights:

Experiments were done on Septembre 27th and 28th in Obermörlen, a release site approximately 30 km North of Frankfurt, home direction: 185°. The release site was chosen, because there pigeons often showed considerable deviations to the east of the home direction in the very first part of the flight in previous experiments [e.g. 8]. GPS flight recorders were switched on 7-30 min before the test. The early switch on served to let the GPS receiver find satellites and acquire a first fix and to check whether the GPS recorder operated. 10 pigeons were released with a GPS flight recorder, 9 tracks were obtained. Every recorded track contains approximately 10 000 recorded positions. Homing times could be measured from all 10 pigeons carrying GPS recorder.

Results:

Observations of flying behaviour

We carefully observed the pigeons, to find out whether there were differences between pigeons carrying the GPS recorders and pigeons not carrying anything, called controls. Pigeons flew well with the GPS recorder, but they tended to fly lower and their wing beat frequency seemed to be higher. Furthermore, some birds carrying GPS disappeared behind obstacles before giving a normal vanishing bearing.

Examples of flight paths:

Most pigeons flew extensive loops immediately after starting their flight (Figure 2). Surprisingly, all the flight path positions beyond a few hundred meters south of Obermörlen village are situated east of the direct line between the release site and the loft. Pigeons deviated as much as 9.3 km to the East of the direct route.

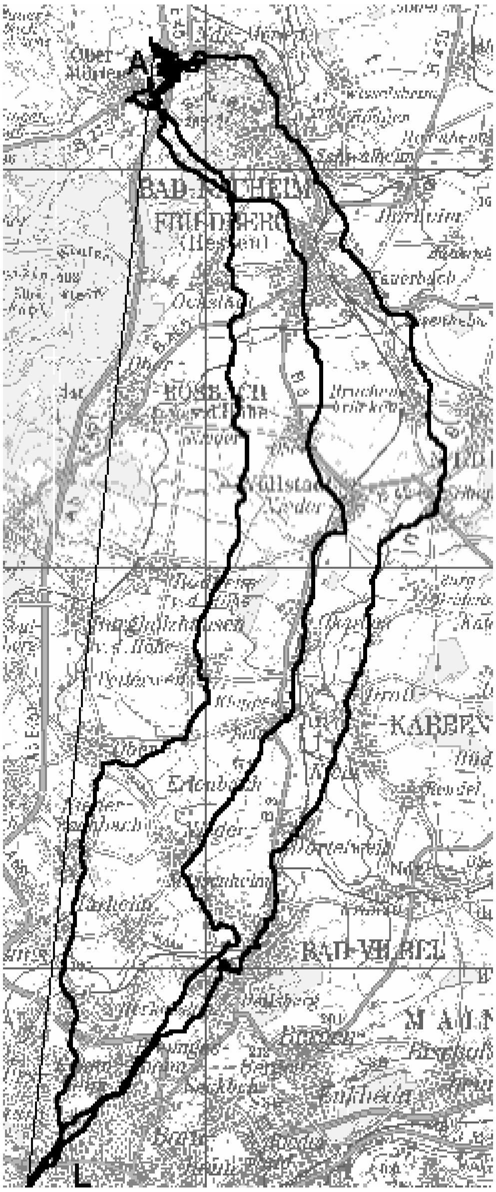

Figure 2: Examples of three complete flight paths, A = Auflaßort = release site = start of flight, L = loft = pigeons' home. The thin, straight line is the direct route between the release site and the loft.

The release site has a special topography. There are two mountains connected by a ridge almost perpendicular to the direct route home, presenting an obstacle on the first few km of the homing flight. The ridge is 70 m higher than the release site and 80 m higher than the valley. The one pigeon flying 90° eastward at the beginning of its flight in Figure 2 circumnavigated the mountain. The other two chose to climb 70 m and to fly over the ridge.

Speed profiles:

The GPS recorder also measures speed, which allows us to determine where and when a pigeon stopped flying. Most pigeons took several breaks during their flight home, ranging from 1 min to 3 h.

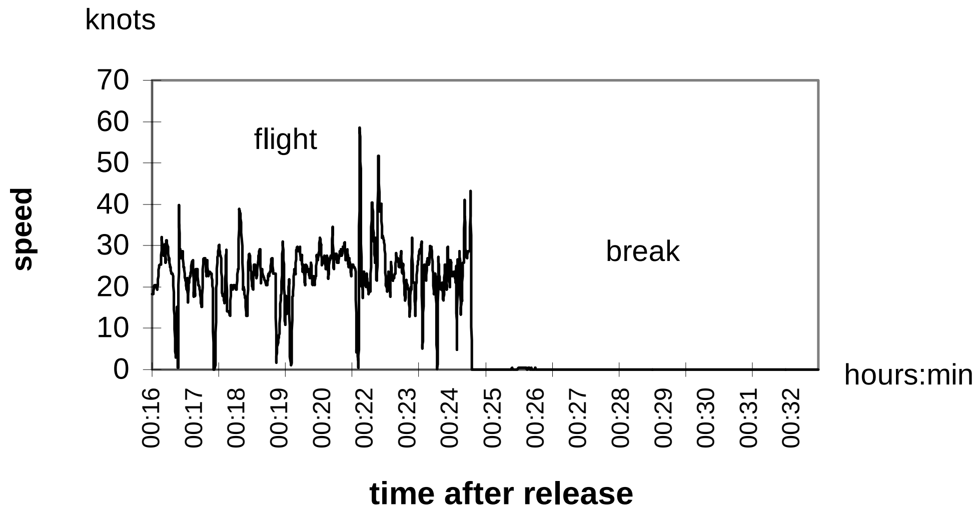

Figure 4: Speed values no. 1000 - 2000 of pigeon no. 356

The GPS recorder's Accuracy of Position :

At the very beginning of the operation of the GPS recorder, some major errors in position occured. Some initial positions deviated by as much as 2.9 to 5.6 km from the true position for several seconds. The reason for these errors is that the GPS receiver had not yet acquired all satellites in view. This type of „switch on“ error was already observed during the development of the GPS recorder. Therefore we took care during the experiments to switch on the GPS recorders at least 7 min before the animals were released. During the flights themselves no sudden big jumps of position were observed.

Several pigeons landed for more than 15 min. This gave us the opportunity to check whether the error in a series of measurements is the one defined by SA, Selective Availability, the standard error built into civilian GPS. We analysed the shift of positions during pigeons' breaks and measured on a map the maximum distance between two positions. In 14 out of 16 long breaks we found that the maximum difference in positions is 100 m.
In the two remaining cases the maximum differences were 110 and 130 m. The last two values are from the two pigeons who made very long breaks. This analysis shows that the positions

measured by the GPS recorders are consistent within themselves and that the error is well within the range of 300 m, the error defined by SA: 100m 95% of positions and 300 m 99% of positions.

Sampling rate:

The high sampling rate of one value per second makes possible a clear resolution of the loops flown (Figure 3). In contrast the same loops are hardly visible anymore with a sampling rate of 1 value every 30 sec. At this resolution it is still possible to see that the flight path deviates from a straight course, but the nature of this deviation cannot be clearly identified.

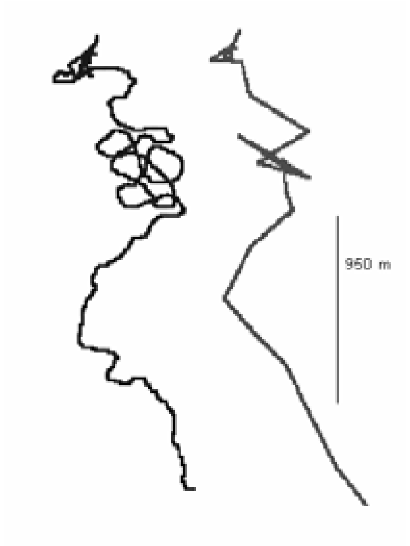

Figure 3: Examples of the initial part of flight path of the same pigeon, with a sampling rate of 1/sec (left) and a sampling rate of 1/30sec (right), right flight path simulated by drawing every 30th value only.

Homing times:

Pigeons carrying GPS took significantly longer to home than two out of three groups of controls of previous experiments. The median value of the GPS pigeons was 133 min, compared to 52, 91 and 56 min of three controls from previous years. In our experiments the fastest pigeon carrying GPS flew without a break and took 52 min to home. The slowest pigeon took a very long break lasting at least 3 hours and came home after 6 hours and 40 min. During the long break the GPS recorder stopped operating.

Discussion:

We have now achieved our main aim of developing a GPS application sufficiently miniaturized to put it on homing pigeons, have them fly with it and obtain accurately measured flight paths.

But there are also two grave limitations of the device with regard to homing pigeons: weight and a residual magnetic field.

The physical size of the device suits the pigeons well, it has been constructed to be more narrow towards the head so that the wings are not obstructed flapping. We are also satisfied with the harness, except for its weight. It fits on the pigeons very well and does not fall off, even though pigeons pick at it with their beaks. The teflon ribbons caused no damage to feathers and skin. The devices stuck very well to the back plate and never fell off in experiments.

Compared to our initial requirements two properties of the GPS recorder are far better than we dared to expect at the beginning of the project: the sampling rate is even higher (1/sec) than our minimum value of 1/5sec and the amount of positions that can be stored is also much higher than the minimum of 1000 we defined at the beginning. We can now store 10 000 positions and would be able to store about 90 000, if the battery lasted that long.

The operation time of 3 hours is the minimum time we wanted. At the moment there is only one battery on the market that has the right combination of very low weight, high capacity and high output current to suit the GPS, so those 3 hours is the best that can be done right now. There is an alternative solution that lasts 30-45 min longer, but that battery weighs several gram more. It could be included into an application for larger animals.

The two major disadvantages of the device remain the weight and the residual magnetic field.

The weight is 33 g plus 7 g for the harness. With the electronics there is no room for further saving of weight at the present state of the art of the components. The 7g for the harness might be reduced by omitting the breast plate or we might use a different technique for attachment.

40 g is still a high weight for a pigeon representing about 10% of its body weight. There is an influence on the pigeon's flying behaviour as can be seen in the long homing times and we also saw from our observations that pigeons lost their ease of flight and flapped their wings with a higher frequency. The long breaks many of pigeons took also indicate that the GPS recorder caused them an additional effort. A study by Gessaman and Nagy 1988 [1] showed that pigeons can be influenced very much by transmitter loads with a weight of 2.5% and 5%. The birds slow down by 15%-28% on 90 km flights and their CO_2 production increases by 41%-50%. Nevertheless we think that the weight of the device is within the physiological range, because the weight of the device is about the same as the weight of the food the pigeons carry after feeding and because all of our birds returned from the homing flight on the day of the release, which implies that the impairment is not too great. Also the orientation may not have been influenced by the additional effort, nor the flight path significantly altered. But it is necessary to further decrease the weight in future versions and the weight is such that the GPS recorder cannot be considered an ideal solution for measuring the flight path of homing pigeons yet.

The device produces a residual magnetic field with a strength of 1,500 nT. This is ~3% of the intensity of the earth‘s magnetic field. In previous work it was shown that very small differences in field intensity of about 0.2% of the strength of the field can make a difference in pigeons' initial orientation [7]. This means that in studies with the GPS recorder the possible magnetic influence needs to be considered as a part of the experimental condition.
The residual magnetic field can be reduced only after more progress in battery technology has been made, since at this moment there is no Lithium battery capable of both supplying the high output current and the right voltage to suit the GPS receiver board.

Conclusion:

Despite its disadvantages the GPS recorder greatly extends the possibilities of measuring flight paths on birds. The GPS recorder has now made it possible to accurately measure, record and plot details of the flight paths with a so far unequalled temporal and spatial resolution, a range of measurement limited only by the power of the battery and a comparative ease of experimental procedure requiring little manpower. It represents a significant advance in measuring technology on animals. Many more species can now be tracked with GPS. When tracking animals with our GPS recorder the animals need to have a weight of at least 500g, travel under the free sky and have to be be recaptured.

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