TrackTag^{TM}- A low-weight, long-duration GPS recording device.

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Overview

Global positioning system (GPS) technology offers a means to compute a position with high accuracy and with relatively small equipment. While recent advances have seen GPS receiver sizes and weights fall dramatically, the power-consumption per fix of GPS receivers precludes their use during extended periods for weight-sensitive applications such as animal-tracking.

This paper describes an innovative GPS achitecture (***TrackTag***^{TM}) that overcomes the power limitations of a conventional GPS approach, permitting a year's worth of operation from batteries weighing just 4.6grams, with the whole unit (unpackaged) weighing approximately 20grams.

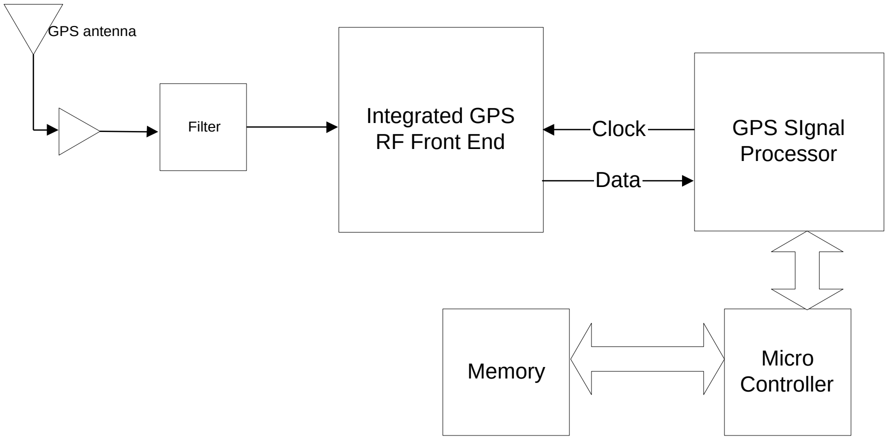
Introduction to *TrackTag*^{TM} Technology

NAVSYS Limited and the School of Biological Sciences, University of Wales, Bangor have recently been awarded a grant by the National Environmental Research Council to miniaturise NAVSYS ***TrackTag***^{TM} Global positioning system (GPS) position logger technology to a size where it can be used for foraging studies of animals such as albatrosses and fur seals, and of migratory studies of animals such as geese and turtles.

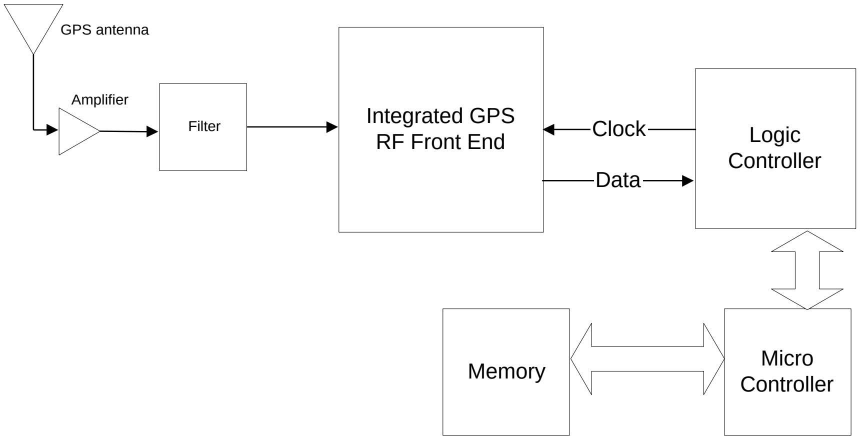
The NAVSYS ***TrackTag***^{TM} system has been developed from the start to use NAVSYS patented GPS technology (Brown & Johnson 1993) with the aim of minimising device power consumption. The main difference between ***TrackTag***^{TM} and a conventional GPS receiver is that ***TrackTag***^{TM} makes no on-board computation of the GPS position. Raw GPS data is simply stored to non-volatile memory for post-processing once the tag is retrieved. By deferring the processing in this manner, device on-time per position fix is reduced from a minimum of 6 seconds per fix (typical GPS "Hot Start" for infrequent position fixes) for a conventional GPS receiver to 60 milliseconds per position fix for ***TrackTag***^{TM}. In fact the power saving of a factor of 100 is even greater, due to the need for a conventional receiver to be powered for at least 20 seconds several times per day to gather "housekeeping " data (satellite ephemeris tables).

Figure 1 shows a block diagram comparing a conventional GPS receiver architecture with the ***TrackTag***^{TM} architecture. Both architectures are similar in the design of the RF front-end and conversion of the GPS data to a pre-correlation data stream. In the case of the conventional GPS receiver this data is then passed to a GPS signal processor, where the actual satellites are tracked and range information is extracted. The final navigation solution is then carried out in the microcontroller using the satellite range information and satellite ephemeris data.

In the case of the ***TrackTag***^{TM} design the raw digital data output of the RF front end is passed via a logic device to the memory for storage without any signal processing. A further advantage of the ***TrackTag***^{TM} technique is that a GPS position fix can be computed even if the tag is only in sight of the satellites for a very short time (as may be the case with a marine mammal breaching). Conventional GPS receivers have a very hard time with such a situation as often the satellites are not in constant view long enough to be acquired and tracked.



A Conventional GPS receiver



B TrackTag Architecture

Figure 1

Application of *TrackTag*^{TM} for Animal Tracking and Comparison with Alternative Tracking Technologies

The ability to acquire physiological and behavioural data from free living animals is highly dependent on the continued development and deployment of modern electronic devices. Once detected, the data of interest are either streamed to the investigator via satellite communication systems, or stored in memory chips until the device is re-captured. These technologies are not mutually exclusive and data may be stored for a while until an uplink can be made to a suitable satellite, but the volume of data that can be sent via satellite is usually quite limited. However, there are numerous model species where recapture of the same individuals over a given period is perfectly feasible (Prince *et al.* 1992; Bevan *et al.* 1997; Boyd *et al.* 1999; Butler *et al.* 1998), or where the tag can be released from the animal and subsequently recovered (Block *et al.* 1998). This has encouraged the use of archival data tags capable of storing large amounts of physiological and behavioural measurements from free-ranging animals, and they are generally proving to be effective and relatively cheap. In particular, archival devices usually have low power requirements and are relatively small.

The dominant device for locating the geographical position of an animal has been provided by the ARGOS system which provides "real-time" information on geographical position, the main drawback being the low number of orbiting satellites which reduce the chance of a satellite being overhead of the tag, and the generally poor resolution (500 m to 2,000 m). Following the recent development of GPS archival and hybrid tags suitable for the tracking of relatively large animals, it is anticipated that the ability to accurately locate geographical position will become cheaper and more commonplace. However, the major technical difficulty associated with conventional GPS tags is that they require an enormous amount of battery power and, therefore, there is an inevitable compromise between battery size, overall package weight and the number of position fixes that can be made in a given time. Currently, there is little prospect of using conventional GPS for high resolution tracking to determine fine-scale movements of animals over extended periods of time. In addition, conventional GPS tags require a relatively long exposure to the satellite code (usually 15 to 120 s) and this may not be suitable for many applications, particularly in a marine (Brown & Kirby-Smith 1996), or cluttered, environment where the object may not be exposed for long enough. This suggest that combining physiological and behavioural data with geographical position using conventional GPS will prove very difficult, except for deployment on very large animals or for very short periods.

1) ARGOS satellite tags - ARGOS satellites calculate global position using the doppler shift of the carrier radio frequency of multiple uplink transmissions received from the tag throughout an entire over pass of the satellite.

The *ADVANTAGES* of ARGOS tags are that:

i) They provide almost real-time information to a remote observer. (ii) They can be reduced to a relatively small mass (20 g to 90 g). (iii) They operate on comparatively low electric current due to the low orbit of the satellites (800 km). (iv) They can provide reasonable life span (around 1 to 12 months) depending on duty cycle and the size of the battery. (v) Every device deployed should provide position information.

The *DISADVANTAGES* of ARGOS tags are that:

i) In general the accuracy of the position fix is only around 1000 m, and the accuracy is further effected by the assumption that the target animal is stationary and at sea level (neither of which may be true, particularly for birds during flight). (ii) There is no information with regard to the altitude or the velocity of the animal. (iii) The timing of the position fix is mainly determined by the presence of a satellite in view, and this can result in lack of position information for 2 hours or more (lower latitudes have worse coverage). (iv) Currently, the ARGOS tag cannot interact or anticipate the presence of the satellite so the tag must be left to transmit for long periods of time to ensure an uplink of reasonable quality. (v) Assuming a mean of 3.5 mA during continuous transmission, this is still quite a large current output to besupplied by a small battery so that, if left on permanently, the life of the tag is greatly reduced. Indeed, it is common practise to incorporate a duty cycle that will turn off the tag for many hours or even days in order to obtain position fixes covering periods of many months. (vi) The ARGOS tags are relatively expensive to buy (approx. £2,000) and, in addition, it is necessary to pay for the satellite time required for the uplinks (this usually doubles the cost).

2) Conventional GPS tags **-** GPS locates position by calculating the phase shift in a Pseudo Random Code which is sent out by 24 orbiting satellites at a specific time.
The *ADVANTAGES* of conventional GPS tags are that:
i) The timing of the position fix is determined by the tag programme and could vary, for example, from once a second to once a day. (ii) The accuracy of the 3D position fix is around 10 m (i.e. includes an estimate for altitude). (iii) Archival GPS tags can be post-processed to yield 3D differential GPS accuracy (DGPS) of better than 10 m and remove the effects of atmospheric interference (iv) The velocity of the animal can also be determined to an accuracy of around 0.1 m sec^{-1} for each position fix. (v) The final position data only occupies a relatively small amount of memory, and thus this data can be sent back to base via ARGOS relatively easily. Thus, every hybrid tag deployed should provide position/velocity data. (vi) Archival GPS tags are likely to be relatively cheap in the future.

The *DISADVANTAGES* of conventional GPS tags are that:
i) GPS is an archival system that stores the calculated positions in on-board RAM memory. It is possible for this data to be retrieved by reacquiring the tag, or by creating a hybrid tag that links the GPS device to the communication system of an ARGOS tag, or by developing a communications link via mobile phone technology where this is in range (only terrestrial coverage at present). (ii) GPS is very power hungry and typically runs at relatively high battery currents of around 135 mA during signal acquisition and tracking. Even in "sleep" mode between fixes a GPS tag uses around 8 mA, so that during prolonged use the tag must be turned off completely between fixes and the device has to "cold start" each time. Therefore, tags which are designed to give reasonably regular position/velocity data for any length of time require very large and heavy batteries. (iii) GPS typically requires around 15 to 120 seconds in order to lock on to the satellites and compute a geographic position, and this requires considerable battery power. (iv) Some archival GPS tags will never be recovered, thus increasing the effective price per position fix.

3) TrackTag^{TM} - is capable of capturing the raw pseudo random code which is broadcast by the 24 orbiting GPS satellites, and simply storing it in non-volatile Flash memory. All the computing and analysis of position and velocity is done back at base once the device has been reacquired. The *ADVANTAGES* of ***TrackTag^{TM}*** are that:
i) The timing of the position fix is determined by the tag setup parameters and could vary, for example, from once a second to once an hour. (ii) The accuracy of the 3D position fix is around 10 m, and includes an estimate for altitude. (iii) Archival GPS ***TrackTags^{TM}*** can be post-processed to yield 3D DGPS accuracy's of better than 10 m and remove the effects of atmospheric interference. (iv) The velocity of the animal can also be determined to an accuracy of around 0.1 m sec^{-1} for each position fix. (v) The time taken to capture the Pseudo Random Code is extremely short, around 60 milli seconds. This means that there is time to take a reading

even when the ***TrackTag***^{TM} is only visible for very brief periods. (vi) The very short data capture time combined with the lack of data processing yields extremely low power requirements (around 0.014 mAh per fix per hour, see below). Consequently, the battery size can be greatly reduced compared to conventional GPS and/or the device can last for much greater periods, depending on the desired duty cycle. (vii) As ***TrackTag***^{TM} makes no calculations there is no such thing as a "cold start". We estimate that over 33,000 fixes could be captured using a single 4 g Lithium sulphur dioxide battery and 384 Mbytes of RAM. (viii) Obviously, with larger animals it will be possible to consider using large amounts of memory or even a larger battery in order to yield extremely high data resolution. (ix) In the future, once established, it may be possible to market ***TrackTag***^{TM} relatively cheaply, thus increasing the number deployed to allow for the fact that some tags may not be recovered. The manufacturer can recover costs by charging for the post-processing work on the recovered tags. (x) The massive memory and battery life capability of ***TrackTag***^{TM} means that tags could be recovered even a few years after deployment and be able to provide huge amounts of positional data.

The *DISADVANTAGES* of ***TrackTag***^{TM} are that:
(i) ***TrackTag***^{TM} is currently an archival system that requires a large amount of memory for each position fix (10 kbytes of RAM per fix). (ii) It is currently only possible for this data to be retrieved by reacquiring the tag. The amount of data is too large to send back to base via ARGOS. In theory, ***TrackTag***^{TM} can be developed into a communications linked system. This will be dependent on the use of mobile phone technology and is not currently feasibly due to the technical difficulties associated with the speed of the communications link required to shift such a large volume of data and the associated power requirements. (iii) Some archival tags may not be recovered.

Table 1 shows a comparison of theoretical 30 g ARGOS, GPS and ***TrackTag***^{TM} devices used for long-duration tracking and examples based on typical animal species.

The ***TrackTag***^{TM} column shows that the present limit on the number of position fixes is not the battery, but the memory capacity. ***TrackTag***^{TM} uses Flash memory of a similar type to that used in consumer electronics such as MP3 players and digital cameras, both of which applications are driving memory capacity up and price down. The available memory size can therefore be expected to grow over the next few years.

Table 1

Satellite tag mass (g)	**ARGOS** (30 g)	**GPS** (30 g)**	***TrackTag***^{TM} (20 g)
Battery mass (g)	20	20	4.6
Battery energy store (mAhr)	1,300	1,300	160
Current required (sleep mode) (mA)	0.003	0.011	0.002
Battery life in off mode (days)	>730 days	>730 days	>730 days
Effective current transmitting/receiving	3.5 mA	150 mA	105 mA
Time to obtain/compute 1 fix in 1 hour (seconds)	Continuous	120	0.07
Current required for 1 fix in 1 hour (mAhr)	3.5 + 0.003	5.0 + 0.011	0.003 + 0.002
Battery life taking 1 fix every hour (days)	15.6 days	10.6 days	1,333 days
Potential total number of fixes per battery	371	259	32,000
Predicted fixes given satellite/battery/memory limit	300 *	259 **	36,000 ***
Potential for re-programming tag to maximise coverage over the course of **1 month**	1 fix every 144 minutes	1 fix every 167 minutes	1 fix every 1.2 minutes
Potential for re-programming tag to maximise coverage over the course of **1 year**	1 fix every 29 hours	1 fix every 33 hours	1 fix every 14.6 minutes

* ARGOS satellite coverage varies with latitude such that it is likely that only around 12 independent fixes would be received per day, yielding a total of around 300 fixes in 25 days. Assuming that the tag must be on for an average of 2 hours to guarantee 1 uplink, leaves 1 fix every 29 hours.

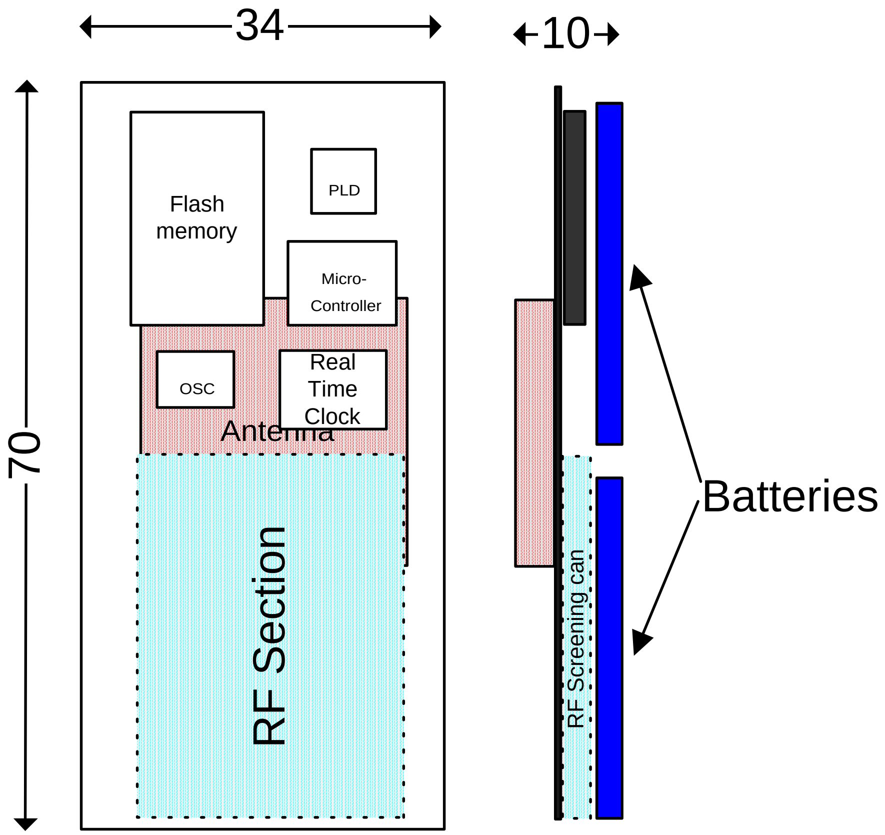
** This analysis is based on the μ-blox GPS-MS1 receiver and assumes a "a cold start" and time to collect ephemeris and almanac.

*** Field trial tags will have 2 x 64 Mbytes of Flash memory which can store around 12,000 fixes (or around 33 fixes every day for a year) but improvements in memory technology are currently very rapid. Samsung predicts the availability of 128 Mbyte Flash memory chips some time in 2001.

TrackTag^{TM} **Device Characteristics**

The ***TrackTag***^{TM} currently under evaluation has the physical characteristics shown in figure 2. The GPS antenna is on one side of the main circuit board (34 x 70mm) with the circuit board acting as the ground-plane for the antenna. The electronic circuitry is on the reverse side of the board with the thin-cell batteries on top of the electronics. Weight budget for the device (without any environmental packaging, but including the batteries) is approximately 20 grams.

Figure 2 Mechanical Layout of *TrackTag*^{TM} Tag



Tests to date have also exercised the batteries down to –20 ºC showing that they have sufficient performance at that temperature. Further trials will eventually be carried out to even lower temperatures.Once experience has been gained with this present device, it is expected that there will be scope for even further weight and size reduction of the device.

TrackTag^{TM} presently logs ambient temperature along with each position fix, and has expansion capability for further environmental sensors (pressure etc). The design also has enough flexibility to permit future upgrades to allow logging of the ancillary analogue data at a higher data rate than the position fixes, and has a wakeup-on-demand mode which should permit position logging from an external sensor that indicates an animal is in a suitable position (e.g. surfacing of a marine mammal).

The ***TrackTag***^{TM} is intialised in the field by connecting a laptop-based initialisation device to a connector on the circuit card. Initialisation parameters such as the interval between position records are set at this time through this link. Download of recorded data is also accomplished by means of this connection when a tag is retrieved.The data file is then sent to NAVSYS for the signal processing to be carried out to compute the position history of the tag.

Project Status

TrackTag^{TM} has undergone numerous trials for vehicle-tracking in an urban environment, with good success. The ongoing programme involves the miniaturisation of the current-generation devices to the dimensions shown above, followed by field trials on a variety of animals. The trials will be carried out through early 2001 into 2002.

Acknowledgements

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