Ultra Low-Power GPS Recorder (TrackTag®)

Alison K. Brown and Peter Brown, *NAVSYS Corporation*

BIOGRAPHY

Alison Brown is the President and Chief Executive Officer of NAVSYS Corporation. She has a PhD in Mechanics, Aerospace, and Nuclear Engineering from UCLA, an MS in Aeronautics and Astronautics from MIT, and an MA in Engineering from Cambridge University. In 1986, she founded NAVSYS Corporation. Currently, she is a member of the Interagency GPS Executive Board Independent Advisory Team (IGEB IAT), and an Editor of GPS World Magazine. She is an ION Fellow and an Honorary Fellow of Sidney Sussex College, Cambridge.

Peter Brown is the Managing Director and Senior Engineer of NAVSYS Ltd. He has A BSc in Electrical Engineering from Imperial College, University of London. He has been involved in GPS hardware and systems design at NAVSYS since 1991.

ABSTRACT

The NAVSYS TrackTag® uses NAVSYS proprietary technology to dramatically reduce on-time for GPS data acquisition. This has a major effect on battery size and lifetime, permitting extremely small package archival GPS tags to be built for applications such as bird and animal tracking. The TrackTag captures raw, unprocessed GPS data in a less than 30 millisecond snapshot for download when the tag is retrieved. Typically data for 64,000 positions can be recorded. The tag provides over 2 years operation with frequent updates. The packaged weight is less than 30 grams. Great flexibility, relative to update rates, is available. The time of data measurement and temperature is recorded. Other data inputs such pressure, humidity, CO_2, etc. can also be recorded from auxiliary sensors.

This paper describes the TrackTag, its attributes, and presents data from recent applications. In particular, the performance of the TrackTag is illustrated with plots of an albatross's journey of 8300 miles in three weeks in the Antarctic. Positioning under heavy canopy in the Amazon is also shown. Future applications for the US Military, Homeland Defense, etc. are covered with further TrackTag improvements under development.

INTRODUCTION

TrackTag has been designed specifically to be optimized for long duration, low weight GPS position recording applications. The predominant current use of TrackTag is by the scientific community for long-duration animal-tracking studies.

Conventional GPS technology has been used for animal tracking applications for some time. GPS tags small enough for some birds have also been available using conventional GPS technology.[1] The drawbacks of the existing technology are the size and weight of the batteries required to support operation over any significant duration. As an example, the miniature (30g) tag used on pigeons in reference 1 has a battery life of, at most, 12 hours, and a typical 1-year duration collar has batteries weighing well in excess of 100 grams (much more if several position fixes per day are required).

TrackTag has been designed to run for at least 1 year, with a position update rate of 5 minutes/fix and a battery weight of less than 6 grams. In addition to size and weight, TrackTag has important performance benefits over a standalone GPS receiver in environments where only fleeting glimpses of the GPS satellites are possible (i.e., fish/diving mammals) in a poor satellite signal environment (i.e., under tree canopy).

RECEIVER DESIGN ISSUES IN ULTRA LOW-POWER OPERATION

Conventional GPS receivers must go through several phases to compute a navigation solution. Typically the battery-powered operational duration desired from the device will require power-down of the GPS unit between position fixes, precluding some of the more recent intermittent-position fix, power-save modes available in more modern OEM GPS receivers.

As a result, the receiver will typically have to carry out a hot-start (valid position estimate, valid ephemeris, time known to better than 100 msec) on each power-on, taking typically a few seconds. Some receivers offer additional low-power modes (quick start (uNav), trickle power (SiRF), snap start, etc.), but typically these only work with intervals between position fixes shorter than (at most) several tens of seconds. In addition to the acquisition time for each position fix, over time the almanac and ephemeris tables will age, requiring acquisition by the receiver of new navigation data; again requiring longer power-on times (the broadcast ephemeris takes 30 seconds to be transmitted, and typically will need updated several times a day). All these times will be seriously affected if the satellite signal is obscured and not easily available.

If we take figures from a modern OEM GPS module (Xemics XE1600, using Trimble's First GPS® architecture), we can estimate the power (*in a close to ideal signal environment*) required to compute position fixes every 5 minutes (ignoring any housekeeping/standby current, or almanac update).

Warm start (to update ephemeris and compute solution):
<32 seconds @ 19mA (4 times per day) = 0.7mAhr/day
Hot start (to compute solution):
<12 seconds@ 19mA (284 times per day) = 18 mAhr/day

To run for a year would require a battery of at least 7Ahr capacity.

In an equivalent environment, TrackTag consumes 2uA standby current and draws 100mA for 30 msecs per position fix. Adding in the 2uA standby current, this equates to a battery requirement of 110mAhr to run for a year with 5 minute position records

TRACKTAG TECHNOLOGY

TrackTag uses NAVSYS' patented TIDGET[2] technology to minimize receiver on-time and power. Figure 1 shows a comparison between the signal processing chain of a conventional GPS receiver to that of the TrackTag. The TIDGET concept involves sampling the downconverted GPS data stream into a digital "snapshot" and passing this recorded data for processing on a remote signal-processing workstation. In many TIDGET applications (radiosondes, sonobuoys), the TIDGET data is immediately transmitted via RF link to the remote workstation; in the TrackTag case, the data is stored to non-volatile onboard flash memory for subsequent download by cable to the processing workstation.

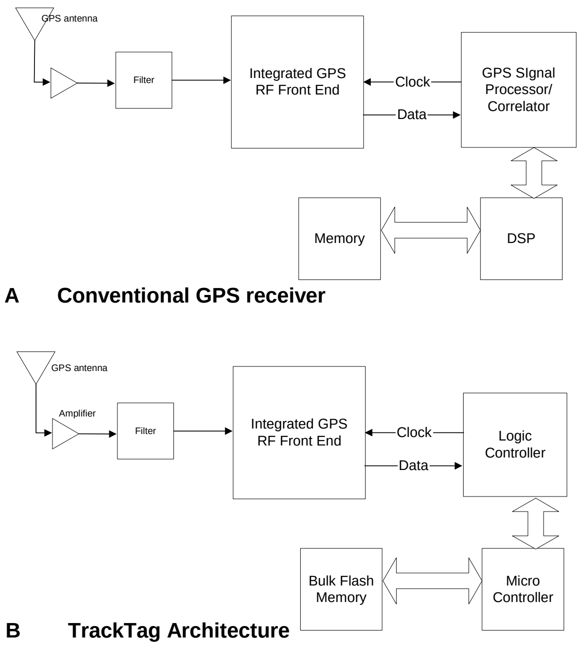

Figure 1 Comparison of Signal Processing

This approach has several benefits over the conventional approach.

Advantages of TrackTag approach

- The TrackTag power-on time is the same low time (20-30 milliseconds) regardless of environment (i.e., no difference between frozen, cold, warm and hot start).
- No need to update onboard ephemeris or almanac tables
- No need for any onboard signal processing.
- Instantaneous Time to First Fix (TTFF) allows operation in environments with infrequent glimpses of satellites (such as diving mammals/fish).
- Proven performance in a poor signal environment (tree canopy)

Disadvantages of TrackTag approach

- Each position record takes up to 10kbytes of memory.
- Data needs post-processed to recover position information.

Enabling Technologies

TrackTag has benefited from recent improvements in two key areas of technology, flash memory and miniature Lithium polymer batteries.

Flash memory chip capacity has been driven up and cost down by the recent emergence of the digital camera and MP3 player markets. Individual flash memory ICs are now available with 1GByte of memory capacity (with 2GByte chips available as samples), giving TrackTag a source of very light-weight data storage and effectively no real limit on capacity for the applications envisaged.

While TrackTag has very low NET power consumption, when the device is actually receiving the GPS signal, it draws close to 100mA at 3.3v. Conventional battery chemistries have not been capable of supplying this instantaneous current in a miniature form-factor (coin-cell, etc.). Recent development of miniature Lithium polymer cells has produced a family of batteries with a very light weight and high energy-density that ARE capable of providing this level of pulse current. TrackTag has been successfully run on a 40mAhr 1.7 gram Lithium polymer cell. Another benefit of these batteries is their relatively low self-discharge rate (albeit degrading at elevated temperatures), permitting their use for deployments exceeding 1 year in duration.

DESCRIPTION OF TRACKTAG UNIT

The present production TrackTag and its packaging were designed with the following goals:

- Capable of at least 1 year autonomous operation with position updates every 15 minutes
- Light enough to be carried by medium sized birds (geese, etc.) (rule-of-thumb is < 3-5% of body weight[3])
- Capable of submersion to 10 meters (for use on diving birds).

The goals were exceeded in every case, with the latest production units now meeting the following performance specifications:

- Capable of storing >100,000 position fixes (one fix every 5 minutes for a year). (This capacity will double by Q4 2005)
- Unpackaged weight (with 1 year battery) <14 grams.
- Different packaging available for diving birds and deep diving fish & mammals.

The TrackTag unit is assembled on a single circuit board approximately 70mm x25mm x 6mm. Functionally, the unit breaks down into the following areas:

GPS Antenna

TrackTag has been designed to be able to use a variety of GPS antennas. For some applications (for example, most bird tracking with a clear view of the sky), the most important aspect of the GPS antenna is weight. In this case, TrackTag can use either a simple ¼ wave whip antenna (extremely light) or an embedded patch. The performance of these antennas is described in a later section.

For other applications, such as large animal tracking under tree canopy, the GPS antenna performance is critical, so either a larger onboard patch is used or an optional external active antenna is used.

Figure 2 shows some of the antennas that have been integrated with TrackTag to date.

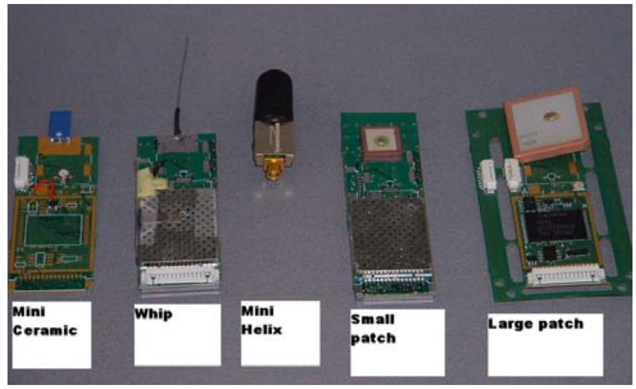

Figure 2 Antenna Options

If a passive antenna is used by TrackTag, the onboard Low Noise Amplifier is used prior to passing the signal to the RF section.

GPS RF Downconversion

The GPS front-end used by TrackTag is a high-performance dual downconversion device, with SAW filtering both at RF and at an IF stage. The front-end has a rapid-lock Phased Lock Loop (PLL) design, and provides a sampled 2-bit data stream (sign and magnitude) to the digital electronics section. The actual sample rate can also be controlled by the digital electronics section.

Digital Electronics Section

The incoming pre-correlation sampled GPS data is stored to the flash memory using a combination microcontroller/ Complex Programmable Logic Device (CPLD) architecture. This architecture permits streaming of up to 2-bits of data at 5Msps direct to the flash memory.

Each snapshot is time stamped by the host microcontroller prior to recording. Temperature is also logged, and additional data fields are available for logging data values from other user sensors.

Current production TrackTags use a single 1GByte flash chip, with production expected to move to 2GByte chips by end of 2005.

Power Management Section

The TrackTag has extensive power management. In normal use, the device is in a deep sleep, with all electronics, bar the Real Time Clock (RTC), powered down. In this mode the TrackTag draws approximately 2uA.

The RTC will wake a housekeeping microcontroller after a pre-programmed time interval. The housekeeping microcontroller then decides whether to wake the tag immediately or to wait for an external stimulus, such as a motion sensor or a salt-water switch to detect surfacing of a diving animal (the salt-water switch firmware runs directly on the housekeeping microcontroller). During this mode the TrackTag draws approximately 6uA.

Once a decision has been made to take the snapshot, the main microcontroller is woken up, and the snapshot is taken. Typical power-on time is 30 msecs in this mode, with approximately 100mA power draw. On completion of the snapshot, the RTC is programmed with the next wakeup time, and the device is put back in deep (2uA) sleep.

Data Download

Data download on TrackTag retrieval is achieved using a laptop and a NAVSYS-designed USB Interrogator unit. The USB Interrogator unit connects to a connector on the TrackTag, and the data download is accomplished by software. The same Interrogator is used to erase the flash memory, set the user parameters (snapshot interval, snapshot data size, etc.) and set the Real Time Clock time prior to deployment. If rechargeable lithium polymer batteries are used, the Interrogator unit also recharges the batteries.

Post-Processing Data

The retrieved data sets are provided by our customers to NAVSYS for post-processing to compute the GPS positions. All processing is carried out using a version of the NAVSYS Matlab GPS Signal Simulation Toolbox, using proprietary low-power signal processing algorithms.

The post-processing uses Rinex Broadcast Ephemeris files to provide the navigation data, and results are provided to the customer along with various optional Quality Assurance parameters.

Batteries

Figure 3 shows some of the batteries that can be used with TrackTag. For comparison, the batteries on the right hand-side are of the size used in a competitor's one-year duration animal-tracking collar (1 hour position update rate).

At the very left of the picture are two miniature lithium polymer cells (both under 2 grams in weight) for the lightest TrackTag applications. These cells will run the TrackTag for approximately 50% of the 100,000 snapshot capacity. The next cell is a 145mAhr 4.5 gram cell that will run the tag to its full capacity for a full year.

At elevated temperature (or very long duration) the self-discharge of the rechargeable cells start to dominate, requiring the use of a primary battery chemistry. The two cells in the middle are examples of cells suitable for this.

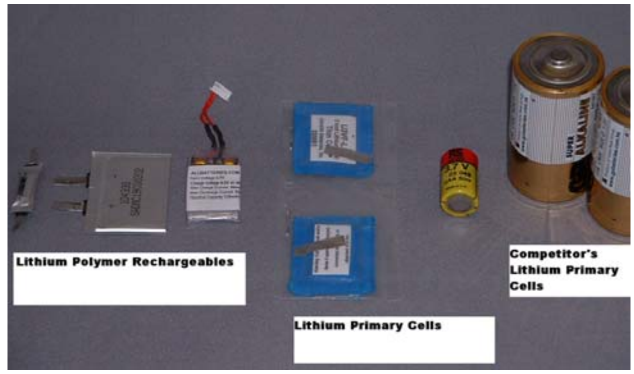

Figure 3 Battery Options

Packaging

For weight-sensitive applications, the device packaging can be a significant proportion of the total weight. TrackTag has used a variety of housings depending on the environment.

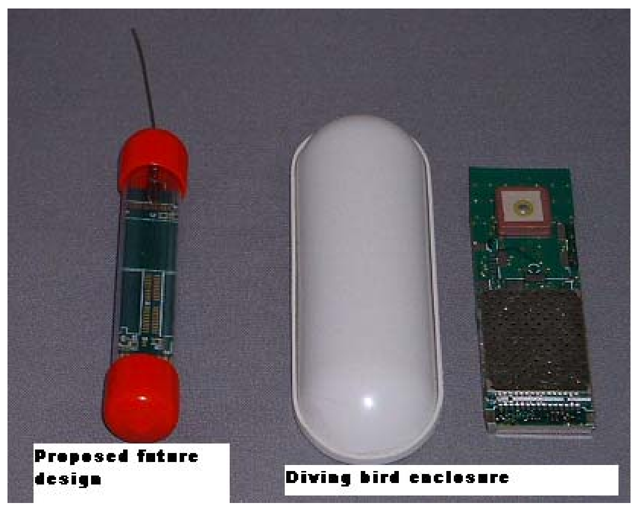

Figure 4 Housing Options

Figure 4 shows the current light-weight housing used on diving seabirds and a proposed future design using a new circuit-board layout and mini-whip antenna. The all-in weight of the seabird housing, TrackTag and 1 year battery is less than 30 grams, with dimensions of 101.5 x 35 x 18mm. Figure 5 shows an early version of this housing attached to the tail feathers of a Wandering Albatross.

Figure 5 Albatross Tag

For other applications, especially under tree canopy, no compromise can be made on the GPS antenna performance. Figure 6 shows a proof of concept waterproof unit with a large GPS patch and groundplane that was successfully used under Amazonian tree canopy.

Figure 6 Prototype Low Signal Tag

Further applications require full pressure-proofing. Figure 7 shows a glass housing rated to 2500 meters water depth. This housing also has feedthroughs to support a salt-water switch to permit instantaneous position fixes when a diving animal briefly breaks the surface. The GPS antenna used in this can be either a mini-helix or a patch, depending on the installed orientation.

Figure 7 Deep Water Tag

FIELD RESULTS

British Antarctic Survey (BAS) Albatross Trials

In early 2004, a series of TrackTags were deployed on Wandering Albatrosses (Figure 8) from the British Antarctic Survey research station on Bird Island, South Georgia, in the Southern Atlantic. These were the first real field deployments for TrackTag and suffered a number of equipment failures (pressure housing failures, and electronic failures). Nonetheless the results were very encouraging.

Figure 8 Albatross

Figure 9 shows the track of a female albatross during a three week foraging trip covering 8500km. The dark dots are positions during darkness, the white during daylight.

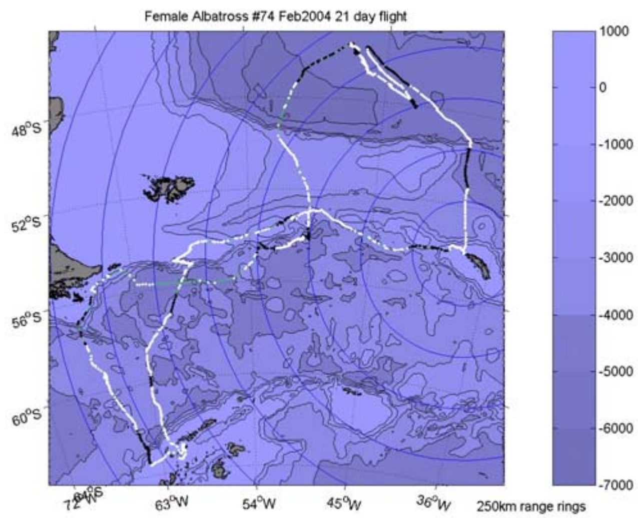

Figure 9 Albatross Track

Figure 10 shows a zoomed-in portion of the track (in Antarctica), showing the level of detail achievable with this track. Previous tracking studies (using Argos or alternative GPS technology) have been unable to provide detail of what the birds have been during through the day, the data being limited to a few position fixes per day. Here, there is sufficient detail to determine when the birds are resting on the surface of the water, etc.

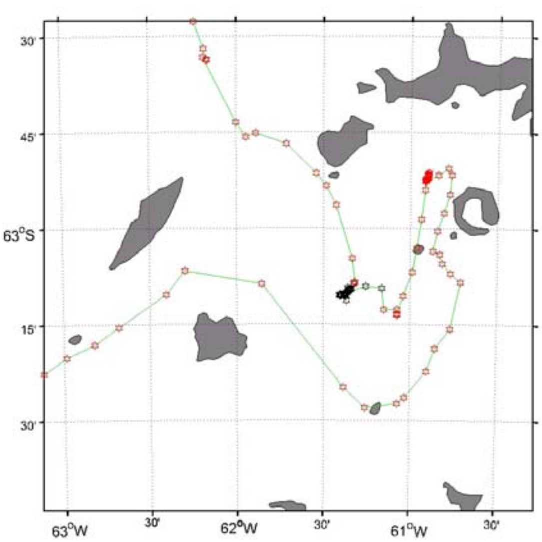

Figure 10 Albatross Track

Amazonian Rainforest Trials

In January 2005 an experiment was carried out to evaluate the capability of TrackTag to function under dense tree canopy, at the Los Amigos Research Center in the Peruvian rainforest.[4]

Conventional GPS receivers had been shown to navigate most of the time under the canopy, but previous attempts at using conventional GPS archival animal-collars had failed (the receivers were unable to acquire the signal from a warm or cold start).

An experiment was carried out using TrackTag to determine the capability of TrackTag in this environment (Figure 11).

Figure 11 Tree Canopy Trials

Figure 12 shows some of the results achieved (TrackTag positions are the red dots). TrackTag managed to compute a position 50-60% of the time (only 10-15% of the fixes were 3-D); with the customer conclusion *"A success rate of over 50% under dense canopy is far beyond any existing technology"*.

A series of TrackTag-equipped animal tracking collars is now (Q2 2005) deployed for an extended duration study of Tapirs in this environment.

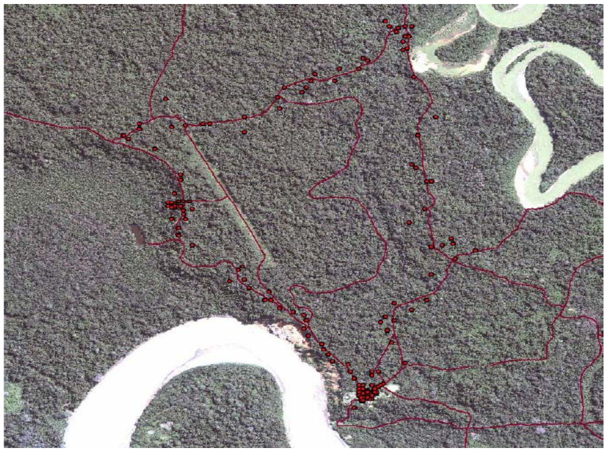

Figure 12 Tree Canopy Results

FUTURE PLANS FOR TRACKTAG

While the main use of TrackTag to date has been to support the biological community, interest has been expressed for TrackTag to be used to support Homeland Security applications, and similar military applications.

Communications Link

A common request regarding TrackTag is the option to add a communications link to permit remote download. While long-range communication of the large TrackTag records (10kbyte per position fix) is probably not feasible, while maintaining TrackTag's benefits in weight and volume due to power consumption issues, NAVSYS have carried out a preliminary series of trials using a low-power short-range 2.4GHz communications link (Zigbee).

Zigbee has some attractions as a communications link with TrackTag, since it is designed for low standby power and relatively high data rates (20-250kbps) at up to 100 feet.

Further Miniaturization

While TrackTag is already very small, we are confident that significant further miniaturization is possible. This would increase the range of birds that could be instrumented with TrackTag. We hope to fly some devices at 12 gram weight on pigeons in 2005, with even further weight reduction possible in the future.

ACKNOWLEDGMENTS

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Thanks are also due to Mathias Tobler, a PhD student with the Botanical Research Institute of Texas, for permission to show the results of the initial Amazonian rainforest trials.

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