COLLAR-INTEGRATED SMALL MAMMAL GPS TRACKER

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ABSTRACT

A position beaconing system for tracking small mammals, such as the Golden Lion Tamarin, was developed and tested. GPS acquires location of the animal. The system utilizes a VHF radio transmitter tuned to 144.390 MHz, which is located in the amateur radio band. APRS was selected as the protocol for position, transmission, and recovery. This allows users to benefit from any existing APRS enabled devices. The beacon was designed by attempting to optimize operational longevity and minimize size. Consequently, the system is implemented on a single board and enclosed for protection. As the system must be comfortable for the mammal, it was manufactured from lightweight components and enclosed in a plastic housing. To attach the case to the mammal, it is connected to a flexible, zig-zag, wearable antenna, which functions as a collar.

KEY WORDS

APRS, Radio, Golden Lion Tamarin, GPS, Lightweight Tracker

INTRODUCTION

Massive scale global deforestation is threatening the lives of countless species. The hunt for natural resources places biodiversity in jeopardy. Maintaining the populations of endangered species is a problem which in part can be solved through engineering design. Animal conservation researchers can make use of information about the location of animals to ensure they are safe and thriving, whether they are indigenous or have been reintroduced to the wild.

One such animal which garners a significant conservational effort is the Golden Lion Tamarin (GLT) Monkey. These primates are native to the Brazillian Rainforest near Rio de Janeiro. With a population of only 1500 roaming southeastern Brazil and 490 captive in zoos, there is a need to study and preserve the species. Reddish-orange in color, the GLTs are the largest of the callitrichines, averaging 10.3 inches (261 mm) in length and weighing 1.4 lb (620 g). Since they usually travel in groups of 2-8, by installing a tracking device on one GLT, the movement of one group can be monitored [1].

To track the GLT, a collar will be placed around its neck, providing GPS coordinates to animal researchers. The small size and weight of the GLT are the impetus for this project. Animal researchers need a small, lightweight, long lasting, and affordable means to track GLTs. Current products on the market do not meet the demands of these researchers as they are too large, prohibitively expensive, or do not have the correct functionalities. Thus, conservationists need an accurate device for small mammals. The size of the GLT and their environment demands a specifically engineered solution. Coordinates of the GLT need to be found and stored, they must be transmitted to researchers, the systems must use minimal power, and the system must be as small as possible. Utilizing a zig-zag, flexible, wearable antenna [2] designed to work with the Garmin DC40 and Astro 320 device, the size of the transmitter was reduced in this work.

DESIGN SOLUTION

The proposed solution is a GPS collar. This requires a GPS receiver as the means of acquiring the animal location, a radio transmitter to send the information to researchers, low power components, and an overall small system. The components chosen and their interactions with one other can be seen in Figure 1.

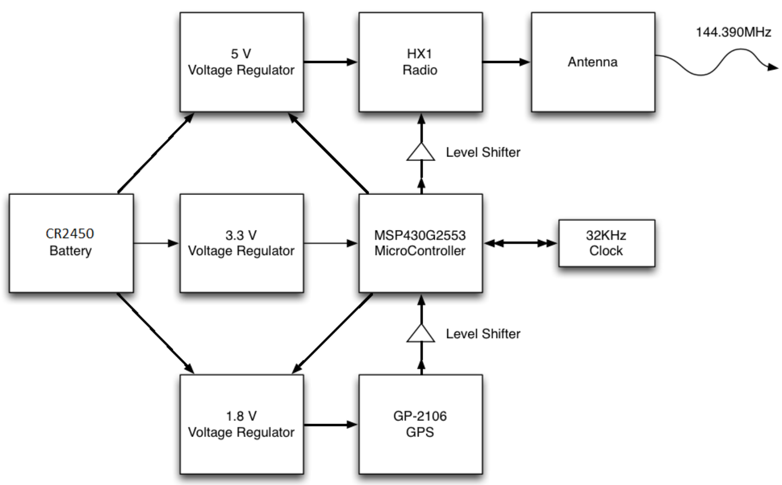

Figure 1: Transmitter Design Overview

Two CR2450 batteries are placed in series to provide 6V, higher than the operating voltage required for the HX1 radio. The batteries connect directly to three voltage regulators, two switching and one linear, in order to power the circuit with 5V, 3.3V, and 1.8V. The microcontroller powered by 3.3V then interfaces with the radio and GPS module in order to communicate and send and receive data. This requires logic level shifting so the components have the correct operating logic levels. The microcontroller also has an external 32kHz crystal connected for low power operation. Not shown in Figure 1 is a resistor ladder which enables sinusoidal signal generation. Then the radio connects to the collar antenna which transmits the information.

The operation of the system in software is also important to consider. Figure 2 shows a general overview of the system operation, although the voltage regulators are not enabled and disabled.

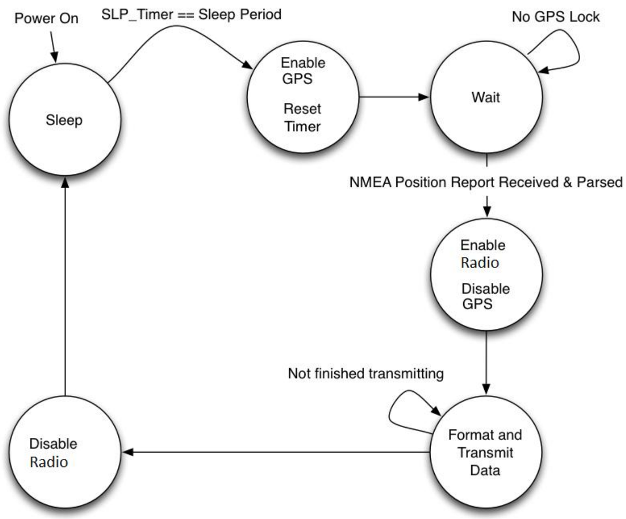

Figure 2: High Level Overview of System Operation

The system is enabled with a switch at which point it immediately goes into a low power sleep mode. A counter is enabled and counts until a user specified time is up. At this point, the GPS is enabled and begins to search for a location lock. Once a lock is obtained, the GPS streams out data about the location of the beacon. This data is parsed by the microcontroller and stored in memory. With the location data stored in the form of an NMEA0183 string, it can be immediately transmitted via the radio, or saved to transmit later. When ready to transmit, the software modem is enabled. The outputs of the microcontroller go to the resistor ladder which is able to encode the data. At the same time, the radio is enabled so the signal at the output of the resistor ladder can be transmitted on the 144.390 MHz carrier frequency.

The GP-2106 GPS receiver is only 21x6x6 mm^3 in size and 3.1 grams in weight [3]. In the rainforest, the GPS signal will potentially be weak because of the dense foliage and heavy rainfall. These factors necessitate that the system have a module with high sensitivity. The GP-2106 is powered by SiRF Star IV and it can receive signals as low as -163dBm. In addition, the GP-2106 has an integrated ceramic antenna. The component is ready to use off the shelf. It may not be as receptive as a receiver with a large external antenna, but this is a necessary trade-off. The major disadvantage of GP-2106, with relation to the rest of the system, is its input voltage is 1.8V, which differs from the input voltage of the microcontroller and radio (3V and 5V) [4][3]. For this reason, the system needs another voltage regulator to lower the input voltage from the battery to 1.8V. Also the logic levels must be adjusted. Unfortunately, this increases the volume of the package required. The GP-2106 will use two pins, 1_V8 and GND will receive power from voltage regulator and connect to ground respectively. The other three: ON/OFF, RXD, TXD pins will communicate with the MSP430 microcontroller [3]. The ON/OFF pin will receive a pulse input from the microcontroller to turn on the system and switch it to full-power mode or hibernate mode. The RXD pin is the main receiver channel to receive commands from the microcontroller and the TXD pin is the main transmitting channel to output the measurement data to the microcontroller.

The GPS unit in the system will capture the signal automatically and transmit the data to the microcontroller through UART. The GP-2106 GPS unit uses a baud rate of 9600 for UART [3].

Since the internal clock in the system is 8MHz, the register is set to 8MHz/9600 = 833.33. The system uses GPGGA strings from the stream of NMEA0183 data, which include longitude and latitude. In the string of GPGGA, a fixed bit will indicate if the GPS received accurate data. The program reads the input of this pin and if it is 1, the microcontroller will record the updated string of data.

SIGNAL TRANSMISSION

PROTOCOL

The Automatic Packet Reporting System (APRS) can be used for much more than position reporting. The reader is encouraged to read more about APRS at www.aprs.org. The APRS exists at a frequency for which a collar antenna could be designed (144.390 MHz). A downside to using the APRS is that it exists, and was created for, the amateur radio bands. Testing was done in a basement and signals transmitted into a dummy load. The amateur bands are recognized by Brazil's spectrum regulatory organization ANATEL.

PACKET FORMATION

An APRS packet is built off of the AX.25 layer-link protocol with several fields in the frame fixed. Implementation of the protocol was specified in [5, AX25]. Essentially, several seconds of specific bit patterns, known as flag bytes, are transmitted to get the receiver ready to demodulate the signal. It is required that the number of bytes in that destination frame equal 7. Further reading on this can be found in [6, APRS Protocol Reference].

WAVEFORM FORMATION

Once the signal has been framed, it will be encoded into either a 1200 Hz tone for a one or a 2200 Hz tone for a zero in a manner known as AFSK at 1200 baud. It is important that when the tone is switched that the phase be contiguous. This can be done effectively by implementing a numerically controlled oscillator (NCO).

The selected MSP430, the MSP430G2553, does not have an onboard digital to analog converter. Instead of implementing PWM to generate the audio signal, a simple four bit resistor ladder was implemented. This reduced the amount of required code by allowing the look up table (LUT) value that was already calculated to be written to the pin register directly. This method also reduces the amount of calculations that have to occur between writing the next LUT value.

RADIO

A Radiometrix HX1 was selected as the sole radio component. The HX1 can be used for FM modulation at a specified frequency upon purchase. This means that it can be fed either digital high-low signals for modulation as fast as 3 kbps or, as was decided, an analog signal that fits this bandwidth constraint. In addition, the HX1 comes in a very small package for a 2 meter radio solution. This package can transmit as much as 300 mW of power without any additional amplifiers. It was decided that should more power be required for better signal propagation an additional amplifier would be added.

ANTENNA

Since a radio with a frequency of 144.390 MHz was chosen, an antenna had to be manufactured using the technique described in [2]. A 26 gauge solid core insulated copper wire was used with 5 mm between zig-zags. The thickness of the insulation worked as a protective barrier to avoid shorts on the antenna. There were 5 wired branches of which 1.5 branches were double wired. The total length of each branch was 105 mm with a thickness of 30 mm. The best frequency obtained was 141.5 MHz at -12 dB; the location of 143.75 MHz occurred at -11.25 dB.

LOW POWER MICROCONTROLLER

In order to extend battery life of the device, the MSP430G2553 will stay in low power mode when it is not receiving or transmitting data. The MSP430G2553 provides three different modes: active mode, low power mode 0, and low power mode 3 [4]. The current usages in each mode are 300 μA, 85 μA, and 1 μA, respectively. For minimum power usage, the system will go into low power mode 3 for a majority of the time. In low power mode 3, the only working clock is the external 32k crystal [4], but for radio transmission, the 8 MHz internal clock is necessary to generate the waveform. For this reason, the clock needs to be switched between these two modes.

In the active mode, the system uses an internal 8 MHz clock; when it is ready to go into the low power mode, the system will switch to external clock by setting ACLK [4]. In the low power mode, the system uses CCR0 up mode interrupt for timing. The external crystal frequency is 32768 Hz and is divided by 8 twice in the program, so the actual frequency is 512 Hz. For this reason, the CCR0 up mode interrupt is set to count up from 0 to 511, so the interrupt will occur in exactly 1 second.

Since the system is designed to log the data twice a day, it will stay in low power mode for nearly 12 hours. Also, entering into and exiting from the low power mode will require two interrupts, which makes the system more complicated.

BOARD

Significant consideration was put into the organizational scheme for the board. Components with related roles in the subsystem operation were placed close to one another. A considerable portion of the circuitry is devoted to power. The three voltage regulators are located on the left of the board and the logic level shifting is along the top. It was determined that all of the electrical components should be on the front of the board with only the battery cell retainers on the back. The radio was positioned in an attempt to isolate other parts of the circuits from RF effects. The microcontroller, because of its central role in the operation is placed in the middle of the board. Pins are broken out for programming and limited debugging, 3.3V, GND, TEST, and RST. There is also a pin at the input voltage to verify that the batteries are still supplying the required 6V.

The outputs of the board are placed along the perimeter: the SMA connector and the GPS ribbon connector. The final dimensions for the board were 2.5 in x 1.6 in, which can be seen in Figure 3.

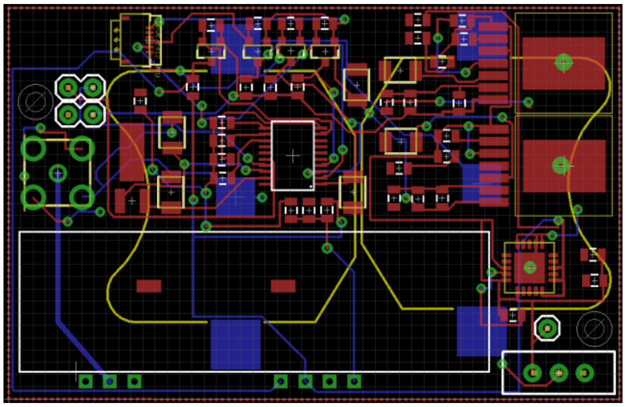

Figure 3: Board Layout and Routing

PACKAGE

A material that was electrically transparent, lightweight, and could be manufactured with a short lead time was desired. ABS plastic is both durable and lightweight, thus it is frequently utilized for electrical applications, making it the material of choice. With 0.25 mm thick strands, ABS plastic can be 3D printed with fine resolution. The walls were designed to be 1.5 mm thick and 3 mm thick at the lip and groove connection between the top and bottom. The overall system measures 2.7 cm x 4.9 cm x 7.3 cm, weighing 105.3 grams. Figure 4 illustrates the 3D printed system.

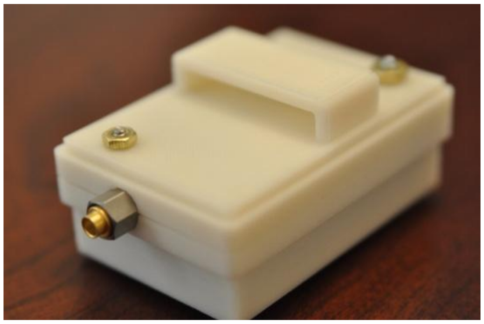

Figure 4: Final Case Design 3D Printed with ABS Plastic

ANALYSIS AND RESULTS

The operation of the system was tested. The ability to obtain GPS coordinates was confirmed along with the amount of time it takes for the GPS receiver to obtain a lock. The generated waveform was recorded and analyzed, though further modification is required to generate a signal which can be demodulated. The antenna was tested to find the loss of power at different frequencies. Lastly, the overall system range and lifetime was tested.

GPS

The outdoor tests indicate that the GPS uses approximately 43 seconds to capture the signal and find the fixed data. Since the system will be used in the rainforest, which may not have strong enough signals, an indoor test was also performed. Although the GPS takes longer to capture signal, depending on the environmental conditions, the system still acquired fixed data indoors. This means the system will likely work in the rainforest.

WAVEFORM AND RADIO

The generated waveform matched what was expected for the AX.25 protocol. However, it was noticed that the bitrate fluctuated quite dramatically with temperature. This is because when the device is in the 8 MHz mode, it is operating off of the MSP430's internal oscillator. Any change in the bitrate will reduce the likelihood of a packet being decoded. It is believed that this is the reason why the ARPS packets were not decoded by either the Byonics Tiny Trak 4 or the KPC3+ receivers. Figure 6 shows the waterfall of two different signals. The top signal is a sample APRS packet that decodes. The bottom half of the spectra plot shows the MSP430's generated APRS signal. What can be seen here is the slight difference. The MSP430 generates, in the initial flag transmission portion, a peak very close to 2200 Hz. Also, the side lobes are shifted accordingly.

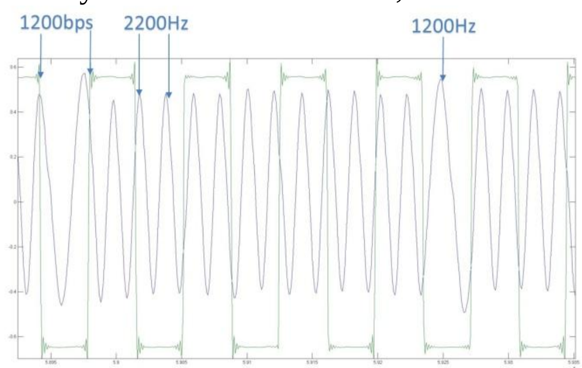

Figure 5: Generated Flag in blue, Baud in green

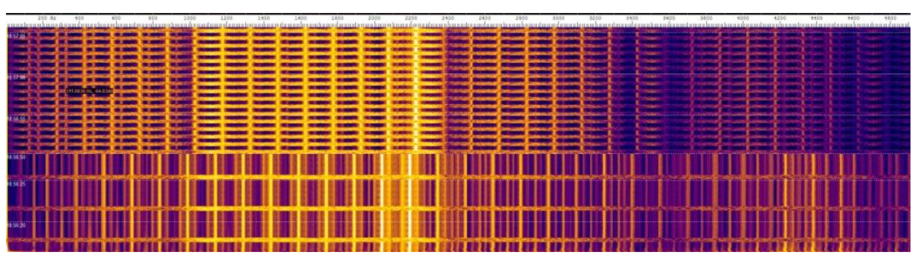
Figure 6: Spectra: Top Half (Sample Packet), Bottom Half (Generated Signal)

Next the waveform of several flags was captured after transmission through the HX1 radio and antenna using a soundcard at a sampling frequency of 44.1 kHz. This waveform can be seen in Figure 7. Analysis of the flag byte showed that the lower frequency portion shown is indeed 1200 Hz and the high portion of the flag is 2200 Hz. However, the expected length of the byte did not match for all the flags.

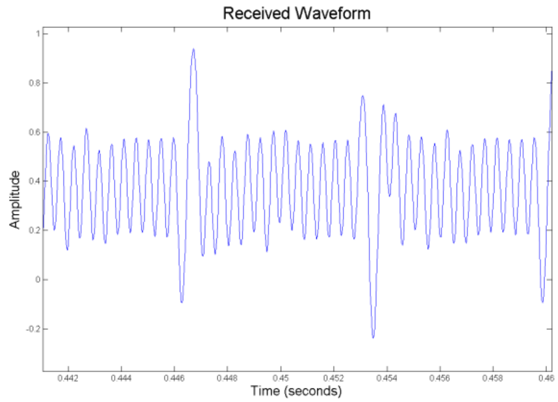

Figure 7: Captured Signal after TX via collar antenna

POWER

Continuous beaconing of the APRS flag (ASCII char' ') can be maintained for approximately 50 seconds before the switching power supplies shut off and the MSP430 is powered down. From this point, the batteries need to be turned off such that they can recover. In order to increase the range as much as possible, it was required to have the system turn on and acquire GPS coordinates, thus drawing 100 mA and then go to sleep for several minutes. The radio is then turned on and transmission can continue. If this process is not done, then the device will not only be drawing 140 mA from the batteries during packet transmission, but also 100 mA for the 40 seconds it takes to acquire the GPS coordinates.

When the system is set to beacon at regular intervals rather than continuously, the lifetime is significantly improved. When beaconing approximately every 76-77 seconds, the beacon lasted just under 46 minutes. This resulted in 36 beacons. The recovery time of 1:16 is much shorter than the system would actually operate in the field and is insufficient for allowing the batteries to recover from the radio current draw. A small order of time in between beacons was necessary to test in a reasonable time frame. The potential of the beacon is evident. If the beacons are spread out to be daily or more, the batteries would recover and the system would be able to operate for days. The longer the device is in sleep mode, the less damage is done to each of the batteries and the device will last longer. Power usage drops significantly when the device is in sleep mode as can be seen from the data taken from a USB current and voltage monitor [8, USB Tester].

RANGE

The maximum range for the zig-zag collar antenna, as determined by field range testing, was determined and compared to that of an off-the-shelf 2M antenna. The results of these tests can be found in Table 1.

Antenna	Range (m)	Perceived Signal Strength
2M off shelf	850	clear
2M off shelf	1000	clear
2M off shelf	1100	clear
2M off shelf	1300	faint
2M off shelf	1400	none
Collar Antenna	500	clear
Collar Antenna	1200	weak
Collar Antenna	1300	none

Table 1: Read Range Data (4/28/2013)

CONCLUSION

The final system was electrically functional and operated as an effective small mammal tracker in several metrics. Unfortunately, the modulation of the signal was not exactly such that demodulation could occur and remotely provide a user with location data. There are certain metrics in which the final system outperforms existing products. In particular, the operational longevity, weight, and cost of the proposed design outperform the products such as the Garmin DC40 collar.

The components selected, along with the ability to vary the beacon frequency, allow the system to operate for extended periods of time, on the order of days. If the beaconing is too frequent, the batteries do not have time to recover from the excessive current being drawn by the radio. However, the goal of the product is to beacon no more than two times a day. The system is modular and can be reprogrammed as well.

The size and weight minimization goal was consistently the most difficult to achieve. Unfortunately, the target weight is a fraction of the weight of the final system. It became clear that this is an inherent limitation to a system involving these components and enclosure. The weight of the system is however appreciably less than that of the Garmin DC40, weighing in at only 105.3 grams compared to the 227.5 grams of the Garmin device [9].

A benefit of this system is that it is entirely open source. This means anyone who is motivated and enthusiastic about the project can make improvements to the design. Thus, this allows the system to be an inexpensive solution for researchers. Bought on an individual basis, the system would only cost approximately $150. At such inexpensive prices, the final design is not only a viable solution to the problem of tracking small mammals, but it is much more affordable compared to existing products, which are less suitable for this application-such as the Garmin Astro 320 which costs more than $500 [9].

Unfortunately, the system came short on several requirements. The maximum range of signal transmission was only slightly more than 0.7 miles compared to the existing 7 miles of the Garmin device. Other metrics, such as further reduction in size and range of operation, could be improved with redesigns. This is only a first operating version of the product and as such, numerous improvements could be made.

FUTURE RECOMMENDATIONS

There are many other ways to track a small mammal. One such viable method would be to place a small radio beacon on the primate that transmits a single pulse every few hours. This pulse would then be recorded at several known positions throughout the forest. Position acquisition can then take place by either looking at the received signal strength of each beacon or via such digital signal processing methods as calculating the difference of the time of arrival. Such systems allow the tracker to be smaller and last much longer by offloading a significant portion of the tracking equipment and software from the primate to a researcher's laptop.

The range of the tracker could be increased by adding an additional amplifier stage to the radio subsystem. However, such an addition will cause an increase in weight/size and decrease in total system lifetime.

If the tracker system outlined in this paper is to be implemented in the Brazilian rainforest, decoding of the transmitted signal using off-the-shelf equipment is required. This means that more time should be spent debugging the AX.25 protocol sections of the code. Additionally, the problem of varying bitrates needs to be further investigated. Use of the MSP430's internal digitally controlled oscillator is not recommended for actual signal generation in conditions with such widely varying temperatures.

Another change that may be implemented in the future is the selection of components that have a common operating voltage. This will not only reduce the cost of the system, but the footprint and wasted power as well. Finding a 3.3V 2-meter radio that has this specification may prove to be a difficult, yet worthwhile endeavor.

REFERENCES

[1] Golden lion tamarin. Wikipedia. Wikimedia Foundation, December 2012. URL http://en.wikipedia.org/wiki/Golden_lion_tamarin.

[2] Fowler, Jared R., Jon M. Austin, Kathy T. Estrada, Mmartin Velazquez, Robyn A. Mohr, and Ruben Sanchez. Small Mammal GPS tracker. rep. n.p.: n.p., n.d. print.

[3] "adh technology gp-2106 sirf star iv gps module with antenna." 2010. ms.adh technology co. ltd. web. 29 nov. 2012.

[4] Msp430g2x53. documentation. n.p.: Texas instruments, 2011. print.

[5] Ax.25 link access protocol for amateur packet radio tech. no. 2.2. 2.2nd ed. tucson: Tucson amateur packet radio, 1998. print.

[6] Aprs protocol reference, August 2000. URL ftp://ftp.tapr.org/aprssig/aprsspec/spec/aprs101/APRS101.pdf.

[7] "adh technology gp-2106 sirf star iv gps module with antenna." 2010. ms.adh tech- nology co. ltd. web. 29 nov. 2012.

[8] Oled power sensor. URL http://friedcircuits.us/docs/usb-tester-oled-backpack-desc.

[9] Garmin Astro 320 GPS Tracker for Sporting dogs (bundle, us).