Low-power Telemetry for Lightweight Position Sensors

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Abstract—This paper describes a solar powered, telemetry-enabled tracking sensor and outlines the design, development and testing associated with the hardware, software and the corresponding base station. The telemetry system utilises New Zealand’s General User 868MHz SRD/ISM frequency band and provides configurable wireless connection for data retrieval. We have achieved data transmission out to a range of 2.4km line of sight. Permanent position monitoring has been achieved, with positions recorded every ~30 minutes.

I. INTRODUCTION

Satellite tracking of wildlife and livestock is well established [1]–[6]. Whilst the species tracked are very different, the desired outcome from the studies are often similar; understanding an animal’s behaviour and group dynamics, as well as the impact they have on the environment. This helps to improve management practises, both of the animal and their environment [2], [3], [7], [8].

The majority of the location monitoring studies, are accomplished with the use of Global Positioning System (GPS) collars for gathering data. These collars weigh between approximately 1 kg [3] up to 2 kg [5] [6]. Recent advantages in sensor technology has allowed for smaller platforms to be developed, using GPS as the main platform sensor [1], [9], [10].

This paper introduces a solar powered telemetry module and outlines the design, development and testing associated with the hardware and software of the module. It was initially designed as a light weight, low-powered location sensor, purely for deployment on wildlife. The sensor utilised Global System for Mobile communications (GSM) for telemetry [1].

The sensor’s main module is the GPS/CPU board. It is comprised of a STM32F103 microprocessor [11] and a Navman Jupiter F2 GPS module [12]. The GPS module implements a SiRFstarIV chipset, which provides quicker and more accurate tracking. It is a low power module, consuming only 14μA in hibernation mode and 13mA when receiving [1].

This paper concentrates on the new telemetry module, which retains and integrates into the modular design of the sensor. With the introduction of the new module, the sensor, shown in Figure 1 has been expanded to include an ear mounted solution for livestock, shown in Figure 2. Utilising the New Zealand available 868MHz SRD/ISM frequency band [13] and an enhanced Wake-On-Radio (eWOR), it provides the sensor with a configurable wireless connection for data retrieval.

II. SOLAR TELEMETRY MODULE

A. Hardware

The telemetry board incorporates a Texas Instruments CC1120 transceiver for telemetry [14] and a BQ25504 nano-power management circuit [15] for solar charging. The dimensions of the telemetry module match the original GPS/CPU module size with which it interfaces. Figure 3 provides a size comparison.

1) Telemetry: The Texas Instrument CC1120 transceiver is a cost effective fully integrated single-chip radio transceiver, which is low power while maintaining high transmission performance, with a range capability of 10km. The transceiver operates in a multitude of frequency bands; 164-192 MHz, 274-320 MHz, 410-480 MHz, and 820-960 MHz. Compromising between the theoretical range (both line of sight and through foliage) and the antenna length required, the 820-960 MHz frequency band was chosen.

A matched balun filter is used in the telemetry pathway. It simplifies the radio frequency chain by removing thirteen passive components from the original Texas Instruments schematic. This reduces the total component count and frees space on the module.
2) Solar Power: Solar charging on the telemetry board allows for an extended deployment of the tags, beyond the limiting constraint of the fixed capacity of the battery. Depending on the application of the tags, small batteries can be used to reduce weight. The two main components in solar power circuitry are the Texas Instrument bq25504, an ultra low power, highly efficient boost converter/charger [13]; and the IXYS KXOB22-12X1 solar panels, high efficiency, monocrystalline solar cells, with a cell efficiency of typically 22% measured at a wafer level [16].

The selection of the KXOB22-12X1 solar panels, complements the TI bq25504 capability to begin operation on only microwatts of power. They have a very good response over a wide wavelength range and the ability to extend run time even in low light conditions.

In standard formation the telemetry board consists of two panels, this is shown in Figures 1 and 2, although concessions have been made to allow for operation of a single panel to be implemented with the addition of a jumper.

B. Software

The position sensor’s software is written in C++ and the functionality is determined by the state diagram shown in Figure 4. The transition to the solar telemetry module has introduced a RADIO_INPUT state, which manages all telemetry communication. The RADIO_INPUT state is only accessed via the FIX_WAIT state, which simplifies the program code and timing. Shifting from the FIX_WAIT state is only achieved via either a radio request interrupt or a fix wait alarm, signifying a GPS acquisition attempt.

As the solar telemetry module is constantly active, the eWOR is a key feature in supplementing the low power nature of the position sensor. Using the internal state machine of the transceiver, the telemetry module spends a short time in receiving mode before going back to sleep. Maximising the sleep component of the eWOR, decreases the overall power consumption of the telemetry module. The sleep time is adjustable via the communication protocol - change configuration request, which has been limited to a maximum sleep interval of 65 seconds.

III. Base Station

The base station provides a two way communication link with individual tags. It provides the received positional information to respective end users for analysis.

A. Hardware

An embedded Linux computer - a Raspberry Pi [17], has been utilised as the base building block. On top of this is a base station shield, providing the tag communication telemetry and an optional DC-DC converter for powering the base station. This setup is shown by Figure 5.

The shield board takes advantage of the header communication pins, that have been brought out from the processor, providing Serial Peripheral Interface (SPI) and General-purpose input/output (GPIO) for controlling the base station telemetry. The header also provides power connection, 3.3V regulated output for telemetry and 5V input for power supplied by the DC-DC converter.
IV. COMMUNICATION

Fig. 4. This figure shows the tag state diagram. From start the sensor drops into a SHELL_WAIT state, which is the main controller state. The HDOP_WAIT and NAV_WAIT states control GPS operations. SHELL_INPUT provides an initial configuration state for a user. The sensor spends most of its time in FIX_WAIT state. This is when the sensor is in its lowest power orientation, waiting for the next GPS acquisition timeout. The new telemetry module has introduced an additional state. This RADIO_INPUT state manages all telemetry communications. Considering code and timing simplicity, the RADIO_INPUT state is only able to be accessed via the FIX_WAIT state.

1) Telemetry: The telemetry on the base station is the same as the telemetry section of the tags' hardware. As the base station shield is not restricted by size or weight constraints, the telemetry radio frequency chain utilises a SubMiniature version A (SMA) connector. This provides it with a wide range of commercial antenna options. Figure 5 shows the base station implemented with a WRT Series antenna, which is centred around 868MHz. It is an unobtrusive, half-wave antenna, which features an integral counterpoise, eliminating the need for a proximity ground plane [18].

Fig. 5. Contained within an IP66/IP67 enclosure, the base station consists of a shield mounted on top of and interfacing with an embedded Linux computer. This shield has a telemetry section similar to the solar telemetry module of the tags and also has a wide range DC-DC converter providing flexibility in the power supplied to the base station. The telemetry antenna is positioned at the front and top of the enclosure. This is a commercial WRT Series antenna, which is centred around 868MHz. Behind this is a Global System for Mobile communications (GSM) module, which provides external access and allows the base station to upload information received from the tags, to a central database.

2) DC-DC Converter: The DC-DC converter provides the base station with the ability to be powered by any DC power supply within the range from seven to thirty six volts. This flexibility allows for the base station to be implemented in a wide range of situations from mobile to fixed.

The main component of the converter is the Texas Instrument PTN78020, a wide-input adjustable output switching regulator. The output has been set to five volts, at which the regulator is capable of catering for loads up to six amperes [19].

B. Software

The base station software is written in Python and utilises multiprocessing and resource sharing. This allows for base stations to poll tags without being unexpectedly interrupted by changes from user inputs. The top level program flow is shown in Figure 6.
**A. Protocol**

The communication protocol between the base station and tag is an extension of native packet handling of the TI transceiver. The design of the protocol has allowed for a range of options to be sent and received. The packet types are split into requests and responses. These are summarised in Table I.

<table>
<thead>
<tr>
<th>TABLE I. CURRENT AVAILABLE PACKET TYPES</th>
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<tbody>
<tr>
<td>Requests</td>
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<tr>
<td>Status</td>
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<tr>
<td>Fix</td>
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<tr>
<td>Instant GPS</td>
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<td>Log</td>
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<tr>
<td>Configuration</td>
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<td>Change Configuration</td>
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1) Requests: Apart from Status and Change Configuration Requests packets, they all follow a similar data field format, comprised of a mandatory tag id field. This allows the base station to restrict its communication to individual tags, retrieving specific response data from intended tags.

2) Response: As part of the communication protocol, all of the response packets begin with a 4 byte tag id, uniquely identifying each tag. The main response from an individual tag is the fix response. It contains information obtained from a single GPS acquisition success. When a fix request is received, a tag will continuously transmit all of its unsent stored fixes to the base station as fix responses.

Table II describes the NMEA-0183 message set that is used by the tags to generate the information contained in the Fix response. The processing of the messages on the tag has been designed to limit unnecessary data that is sent.

**V. TESTING AND RESULTS**

The base station and tags have been field tested, monitoring the performance to identify any bugs or weaknesses.

**A. Range**

The range of the telemetry module has been tested using a tag mounted to a bike helmet. Figure 7 shows a snapshot of the marker map from the web-based user interface. The base station is represented by the green star in the cluster of GPS fixes. The red markers indicate GPS fixes and the green arrows represent successful base station-tag communication.

As part of successful base station-tag transmission, two quality factors are appended to incoming packets. These quality factors are Received Signal Strength Indication (RSSI), which is the signal strength received at the antenna. The Link Quality Indicator (LQI), is a metric of the current quality of the received signal. The lower the value the better the quality. The combination of these two factors provides an indication on the success of transmission.

On the marker map the solid blue circle indicates the farthest direct line of sight transmission of 2.4km and has a RSSI of -84dBm and LQI of 129. Whilst the two dashed yellow circles are transmissions where the line of sight is impeded, the farthest is 1km and has a RSSI of -98dBm and LQI of 145.

The telemetry transceiver was configured to accept signal strengths down to -110dBm. This indicates a greater direct line of sight could be achieved. This may also be the case for the impeded line of sight, however, the higher LQI indicates a lower signal quality and further range may not be possible.

**B. Power Consumption**

The telemetry board was designed as a low powered platform allowing for a shorter fix interval for the tags. With the addition of the solar power, the design allows for an extended run time. Figure 8 shows battery usage over time for a test tag. The data represents a starting fix rate of 30 minutes with a full capacity battery.

As the battery voltage drops, the adaptive fix interval responds to set battery voltage thresholds, lengthening the fix interval. The algorithm adjusts the length of fix interval in accordance with the battery voltage, until it able to reach a sustainable charge cycle. Figure 8 shows the period between the 6th of October, 2014 and the 28th of October, 2014. This test
Fig. 7. On-line snapshot of a marker map containing location and telemetry data from a test tag. The red markers indicate GPS fixes and the green arrows represent successful base station-tag communication. The base station is represented by the green star in the cluster of GPS fixes. The solid blue circle indicates the farthest direct line of sight transmission of 2.4km and has a RSSI of -84dBm and LQI of 129. The two dashed yellow circles are transmissions where the line of sight is impeded, the farthest is 1km and has a RSSI of -98dBm and LQI of 145.

tag sustained a charge cycle finding an equilibrium between 3.8 and 3.9 volts.

The effect of the solar charger on the battery is also clear, by the periodic oscillation in the battery voltage. It is a good indicator on the light conditions available on each day. Clear, very sunny days allow for the tags to be fully recharged; while low light conditions, such as cloudy days cause the average periodic oscillation to drop to a lower voltage.

VI. CONCLUSION AND FURTHER WORK

The development and integration of the solar powered tracking telemetry system with the position sensor for livestock and wildlife, has demonstrated practical transmission range and successful implementation of the adaptive data acquisition algorithm.

Field testing of the system has achieved data retrieval up to a range of 2.4km line of sight, with indications greater range is possible.

The use of the adaptive data acquisition algorithm has shown the position sensor is capable of adjusting to different light conditions. Theoretically, this removes the position collection limit of the battery capacity. However, the adaptive algorithm requires a sensible initial fix interval to be effective.

With the modular design providing the proof of concept, the next step is the combination of the separate modules into a single form factor, which better represents the current design of ear tags.

REFERENCES

Fig. 8. A plot of the battery voltage of a stationary test tag starting the 5th of September, 2014 and ending the 28th of October, 2014. Clearly apparent is the time dependent oscillation of the voltage. The period of this oscillation is equal to one day-night cycle. The adaptive data acquisition algorithm is also evident. The algorithm adjusts the length of fix interval in accordance with the battery voltage, until it is able to reach a sustainable charge cycle. In the period between the 6th of October, 2014 and the 28th of October, 2014 this test tag sustained a charge cycle finding an equilibrium between 3.8 and 3.9 volts.


