A General-Purpose Low-Cost Compact Spatial-Temporal Data Logger and Its Applications

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Abstract – This paper presents design details of SEAL, a general-purpose low-cost spatial-temporal data logger. The SEAL module includes GPS, Lithium-ion polymer battery, high-density flash memory and a USB interface. The main features include: low cost, very large size XML-based data logs, low power consumption, flexible sensor attachment, and an optional Wi-Fi interface for Internet-enabled data. It is compact, self-contained and light-weight—suitable for a UAV (unmanned aerial vehicle) payload. In fact, our general-purpose SEAL module can turn any mobility platform into a mobile sensor. For example, we have interfaced CO\textsubscript{2} and NH\textsubscript{3} sensors with a SEAL module and attached the pack to a car which can be driven to map the CO\textsubscript{2} and NH\textsubscript{3} in a region of interest. The XML-based data logs allow interoperable post-processing in every modern computer operating system and display in desktop mapping applications such as Google Earth and NASA WorldWind.

Keywords – geo-spatial data, XML, geo-logging, reality mining, GPS, flash memory, GPX, USB, low-cost datalogger, mapping, UAV

I. INTRODUCTION

The need for a small, ubiquitous sensing is growing all around us. Applications such as tracking climate change, pollution or other environmental data are drawing increasing attention from both academia and industry. Although it is relatively how such data changes over time, rarely is the change over both space and time studied. The addition of this 4th dimension to scientific data while keeping low cost and providing large datasets is the goal of the Spatial Environmental Autonomous Logger, or SEAL platform.

A confluence of development has set the stage for concepts like SEAL: Cellular telephone development has driven mobile electronics to be smaller, lighter, more power efficient, and less expensive. Power densities for batteries such as Lithium-ion polymer (Li-Poly) have been increasing. GPS receivers have been dropping in price, size and weight, and increasing in sensitivity. Finally, flash memory has made steady progress as an inexpensive and reliable source of large, long-term storage.

Typically, the types of tasks SEAL is suited for are accomplished with handheld Windows Mobile devices (such as in [5], but these units are neither inexpensive, nor power efficient, nor light-weight. Much like these devices, SEAL includes Wi-Fi and logs its data onto a flash memory card with a Microsoft FAT16 file system.

Development work on SEAL is being done in stages. The first hand-built prototype for the datalogger is shown in Fig. 1, and did not include the power system, final GPS unit, or the eventual Wi-Fi interface. Figure 2 includes all of these parts, as detailed in Sec. III below.

The main contribution of this paper is to showcase and document the design of a new generation of general-purpose datalogging equipment enabled by the latest technology advancements, including power and space usage.
both data memory and scope than SEAL. Other flash-memory based projects such as Ocean Bottom Seismometers[14] (OBSs), and multi-year environmental logging projects like the solar-powered autonomous underwater vehicle[7] developed by the Autonomous Undersea Systems Institute (AUSI) have similar structures to SEAL, but their design paradigms remain specific to their particular projects. A more similar project is Cartel by MIT’s Computer Science and Artificial Intelligence Laboratory[4]. As GPS becomes more integrated with everyday life, organizations such as Microsoft Research Asia[20] have made great progress in visualization and storage of GPS logs and movement history. Other projects such as CarWeb[5] are taking place to analyze traffic systems.

III. SEAL DESIGN DETAILS

SEAL is composed of relatively low-cost components, and is based on an Atmel AT90USB1287 8-bit RISC microprocessor[3].

![Figure 3. SEAL System Diagram.](image)

A. Power system

SEAL’s power system is based on a high-performance Lithium-ion-polymer (Li-Poly) 1200mAh single battery cell. A Texas Instruments TPS63001 80-90% efficient single-inductor Buck-Boost converter[16] provides system power. Safe battery charging is handled by a National Semiconductor LM3658 USB-compatible Li-Poly charging chip[12] which also allows for higher-current charging from an alternative source, such as an AC adapter. A Linear Technologies LTC1998 low battery detect chip[10] rounds out the power system design, with a hardware interrupt to give the CPU warning of an impending system power loss. Actual non-sleep run times have been in line with the anticipated 8 hours at 80% efficiency (1200mAh × 0.80/115mA = 8.3h).

![Figure 4. SEAL Power Block Diagram.](image)

<table>
<thead>
<tr>
<th>Part</th>
<th>Current @ 3.3V (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmel CPU</td>
<td>20</td>
</tr>
<tr>
<td>u-Blox GPS</td>
<td>50</td>
</tr>
<tr>
<td>MicroSD Card</td>
<td>20</td>
</tr>
<tr>
<td>LEDs</td>
<td>7</td>
</tr>
<tr>
<td>EasySen SBT80</td>
<td>8</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>115</strong></td>
</tr>
</tbody>
</table>

![Table I. SEAL POWER BUDGET](image)

SEAL’s power system also includes a Texas Instruments TPS2097 High-Side MOSFET Switch[17], allowing the main elements of the system to be shut down to allow various low power modes (see Fig.5) for instance, to shut the Wi-Fi interface down when not in range of an acceptable access point. With the TPS2097’s over-current protection, this power distribution scheme also gives power separation to the various subsystems; if one part fails and shorts its power rail, the other systems and main CPU will not be affected and SEAL can carry on in a degraded mode.

![Figure 5. SEAL Power Distribution Diagram.](image)

B. SEAL Sensor Interfaces

SEAL is foremost a sensor platform, and as such has interfaces for both analog and digital sensors. SEAL’s sensor interface includes:

- 8 individual general-purpose digital I/O (GPIO) lines (alternatively exposing the CPU’s 2-Wire Serial Interface for IIC communications).
- A dedicated external hardware interrupt CPU line.
- 3x pulse-width-modulation (PWM) outputs (alternately 3 more GPIO lines)
- Switched Analog and Digital 3.3V sensor power
C. GPS Integration

SEAL’s GPS unit is the LEA-5H from u-Blox AG[19], and is one of the most advanced consumer GPS modules available. In its 22.4x17.0mm, 2.1g package, it has a 50-channel satellite tracking engine, -160dBm maximum sensitivity, and includes flash memory to retain GPS almanac and configuration data. In addition to the reception of standard American GPS signals, the LEA-5H can also receive European GALILEO positioning signals. A passive ceramic patch antenna on a ground plane is included with SEAL, but may be upgraded to a helical model in the future for better coverage in various orientations.

D. Data Memory

While traditional dataloggers—even in the last 10 years—use EEPROM or other small and generally expensive memory[13], SEAL uses cheap, large, consumer Flash Memory in the form of MicroSD cards. Using Microsoft’s FAT16 file format makes SEAL’s data logs easily accessible from any modern Operating System. Many laptop manufactures include MMC/SecureDigital card readers standard with their PC hardware, which natively read MicroSD memory cards. MicroSD cards are very small (15mm × 11mm × 0.7mm) and very light (0.40g), and their capacities are expected to continue increasing. SEAL has been tested with cards ranging from 512MB to 2GB (the maximum physical limit for the FAT16 filesystem), although at the time of this writing, the largest MicroSD card is 8GB.

E. USB Interface

A USB interface is included in SEAL to give it maximal usability for many applications. At a base level, the USB connection charges the Li-Poly battery. Atmel, Inc.’s Flexible In-system Programmer Software, or “FLIP,” in-system programming tool allows for AT90USBXX firmware upgrades over the USB, so users can flash custom or updated firmwares in-field by starting SEAL in Device Firmware Upgrade (DFU) mode. Using standard USB device profiles such as the generic Mass Storage Device (MSD) device class, future software upgrades will allow users to retrieve data stored on the MicroSD flash card over the USB interface, or change logging parameters such as data channels, frequencies, Wi-Fi settings, etc.

F. Optional Wi-Fi Interface

Wi-Fi is a ubiquitous wireless data-link layer networking standard and adds many possibilities to SEAL. Although Wi-Fi has large power requirements (up to 750mA burst and around 400mA steady-state), a Wi-Fi + TCP/IP enabled SEAL unit can report all or some of its data to any server on the Internet, or periodically upload collected data to some central data server. It is also possible to communicate with other SEAL units in range, effectively converting the SEALs into a sensor mesh network.

A Lantronix Matchport b/g unit[9] has been tested with SEAL as seen in Fig. 2.

G. User Interface

A minimal, yet functional user interface is included with SEAL. Three LEDs indicate:
1) Charging status of the Li-Poly battery.
2) GPS lock status.
3) System heartbeat/logging indicator.

Three push buttons are also part of SEAL:
1) Activates Atmel’s USB DFU during start up (also available as a soft button during operation)
2) A dedicated soft button for stopping and starting the logging process
3) A button attached to an external hardware CPU interrupt allowing an operator to press the button and create an “on demand” data point.

IV. Data Storage

SEAL logs its data on a MicroSD flash card, in a Microsoft FAT16 filesystem. The formatting chosen for the data log files is GPX: the GPS eXchange Format[18]. This is an XML schema describing GPS (and other) data such as Routes, Tracks, and Waypoints. SEAL’s data is logged as successive Track points (<trkpt></trkpt>) in a single Track (<trk></trk>)

The GPX format allows for full interoperability in all modern operating systems as well as full extensibility for any possible sensor or data requirements. GPS also allows use of modern programming development and analysis tools (PERL, C#, MATLAB, etc.) for working on SEAL data. Additionally, using standard libraries and a minimal amount of interpreting code, it is possible to transfer data logs from any number of SEAL units into a relational or object database such as MySQL[11] or GOODS[8].

The GPX format produced by SEAL also loads directly into Google Earth and NASA WorldWind, allowing instant, 3D, plotting of a data log. Using mapping tools such as GPSVisualizer[1], it is possible to produce output with color that varies by a sensor reading. For instance, plotting CO2 on the map gives a colored visual representation of the spatial concentration of the gas.

SEAL’s hardware includes a warning external hardware interrupt signal that allows the CPU to close the GPX file...
and end the logging session when the battery is depleted (see Fig. 4) to avoid corrupting data.

V. SENSOR OPTIONS

SEAL's first conception included an interface to the EasySen Technologies SBT80 sensor board [6], giving the system the following default sensors:

- Visual Light
- Infrared Light
- Acoustic Sound Pressure
- Temperature
- Dual-axis Magnetometer
- Dual-axis Accelerometer

The SBT80 is commercially available and fits the SEAL paradigm of small, light, low-power sensing hardware.

SEAL has also been equipped with powered CO$_2$ (model MG811) and NH$_3$ (model SP-53) gas sensors, from Hanwei Electronics Co., and FiS, Inc., respectively. These sensors are small and light, but require approximately 1.2W each to power their heating elements.

Other possibilities include pollutant, air pressure, and humidity sensors.

VI. RESULTS

Figures 7 and 8 show plots of uncalibrated data taken during a car trip. A SEAL module was attached to the hood of a car via a magnetic mount and the sensors were allowed to warm up. During the drive, various vehicles were followed and changed the relative amounts of CO$_2$ and NH$_3$ in the data log.

VII. APPLICATIONS

While SEAL's small form factor and low cost are advantages, the integrated GPS receiver allows not only for spatially-related data sets but for logging scenarios that are unique to SEAL.

A. UAVs

Small Unmanned Aerial Vehicles (UAVs) are growing in popularity for various monitoring purposes, both military and non-military. Typically, UAVs send their telemetry back to their ground station in real-time, using various kinds of medium to high-speed data links. However, for scenarios that do not demand hard real-time data such as long-term environmental monitoring (Fig. 9) or very high resolution experimental data which produces large data sets, it is possible to use the GPS receiver to enable the Wi-Fi interface only when the UAV flies nearby the co-ordinates of a known access point (Fig. 10), and put the UAV into a holding pattern until the downlink is finished.

Use of Wi-Fi in this manner allows for maximum data transfer and maximum run-time, given that the transmit power required decreases as a function of $r^2$ (where $r$ is the transmission distance).

Additionally, given SEAL's ability to track multiple sensors and data sources, a UAV (or UAVs) fitted with meteorological sensors for barometric pressure, temperature, and relative humidity can estimate wind speed in-flight and serve as a mobile meteorological station.
B. Fleet Vehicles

SEAL can be used on a single vehicle or a fleet of vehicles such as mail trucks, garbage trucks, or public transportation systems such as city buses. Such an arrangement would give many different sets of data from the same or similar routes over time, and could help model changes in environmental status such as pollutant levels over different times of the day, week, or year.

With SEAL’s external hardware interrupt connected to a device that “counts” passengers on a public bus, passenger trends such as crowd tendencies over times and routes can be established, and the system can be adjusted to accommodate more popular stops and routes, increasing the efficiency of the whole public transportation system.

VIII. CONCLUSIONS

In this paper we have presented SEAL, the Spatial Environmental Autonomous Logger. We have detailed its construction and implementation, and explained many of the engineering decisions that contribute to its unique design. SEAL uses a highly-efficient Buck-Boost power system supplied by a single Lithium-ion polymer battery cell, includes a GPS receiver for spatially-relevant Geo-referenced data logs, and stores gigabytes of information on inexpensive MicroSD flash memory cards. With a USB interface for charging and data transfer, and an optional Wi-Fi interface, SEAL’s design is very flexible and creates new and interesting datalogging possibilities. SEAL uses the GPX standard for logging data, allowing for data and location to be coupled in a universally readable and extensible format which can be opened directly in Google Earth or post processed for more in-depth data analysis. While SEAL’s sensor options are practically unlimited, it has been tested with a base set of sensors (namely the EasySen SBT-80 suite) as well as CO₂ and NH₃ gas detectors. Applications for SEAL are many and include payloads on Manned or Unmanned Aerial Vehicles, and tracking environmental changes using over static routes such as using fleets of vehicles such as postal carriers and city buses.

REFERENCES