Development of a low-cost magnetometer for auroral alerts and citizen science

Lancaster University

Steve R. Marple and Farideh Honary

Lancaster University, Lancaster, UK

s.marple@lancaster.ac.uk
f.honary@lancaster.ac.uk

Introduction

Our aim was to design a complete magnetometer system that could be built by anyone with competent soldering ability and without requiring access to extensive workshop facilities. For easy installation a battery-powered, wireless system was desired. The system we designed is composed of two main parts, the remote sensor unit and the base unit.

Remote sensor unit

The sensor unit contains the fluxgate magnetometer sensor, microcontroller, battery and a small radio transceiver module. All parts are fitted inside a waterproof enclosure which is constructed from a 1m length of standard 110mm diameter soil pipe and partially buried. The single fluxgate sensor, analogue to digital converter and 5V analogue power supply are positioned approximately 0.85m below ground to ensure a stable operating temperature (typically $< 0.25\,°C$ diurnal variation). Sensing, timing and communication are controlled by a custom embedded microcontroller, a derivative of the popular Arduino system. The microcontroller, battery and radio module are mounted in the top of the enclosure, above ground level.
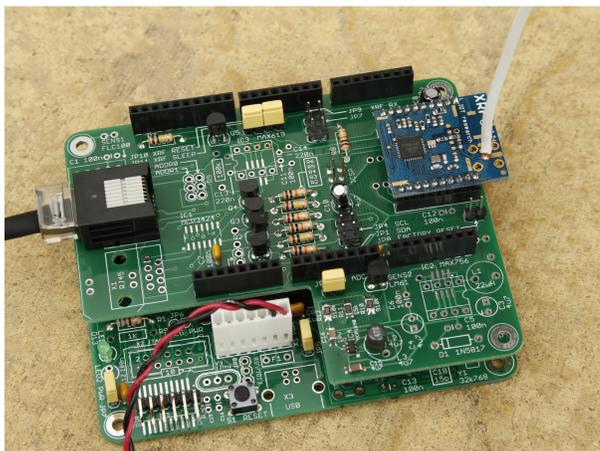
Microcontroller board (bottom), logic-level interfacing and power supply board (middle) and radio module (blue, top).

Data packets are sent from the remote system to the base unit, which replies with a message acknowledgement that includes the current time, and optionally, commands to alter timing, sensing and communication parameters. The acknowledgement can also instruct the microcontroller to begin downloading a new firmware image. All communication packets are signed to ensure integrity against both natural sources of channel interference and malicious, spoofed messages. A communication buffer can store up to 10 minutes of magnetometer data samples for subsequent retransmission. The wireless link has a maximum distance of 50m. The sensor is switched off and the microcontroller put into sleep mode between samples to obtain approximately 4 months of operation at 30s cadence from the battery (2 D cells). Most of the electronic components are through-hole with some surface-mount ICs.

Base unit

The base unit is a Raspberry Pi single board computer with a radio transceiver module fitted to either the expansion port (GPIO) or a USB port. A Python program saves the data to an SD card and enables configuration changes to be sent to the sensor unit. The data is periodically uploaded to a central server using an rsync-like protocol over HTTP(S); real time data transfer by UDP packet is also implemented.

Power over Ethernet magnetometer

Power consumption considerations limit the battery-powered version to to infrequent, single-axis measurements. To counter this we developed a power over Ethernet (PoE) model capable of providing 3-axis measurements at 5s cadence. The fluxgate sensors are always powered which gives significantly better noise performance and stability. When an optional GNSS module is fitted highly accurate timing is obtained from GPS and GLONASS satellites. The sensor unit can be located further from buildings as the maximum distance is limited by the Ethernet maximum segment length of 100m.
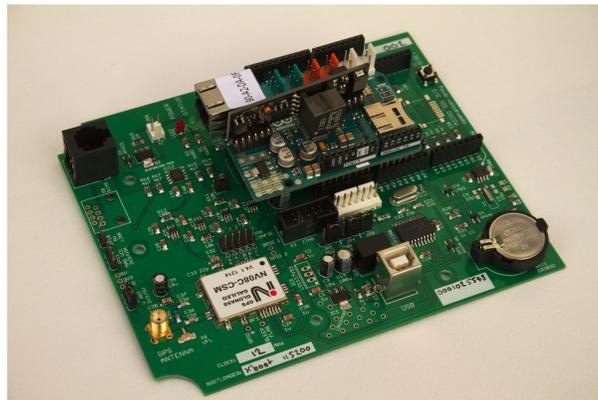
Microcontroller board for the PoE magnetometer.
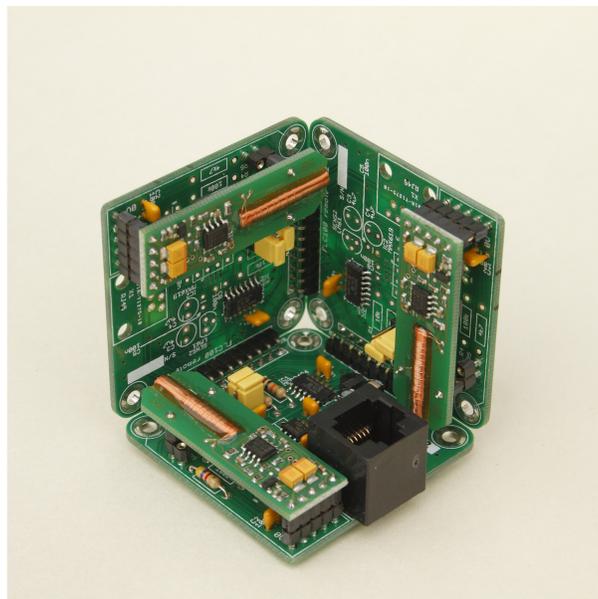
Three-axis sensor. We take advantage of the high-precision with which PCBs are made to avoid the need for custom mounting hardware. Each sensor has its own ADC which enables simultaneous sampling for each axis. The battery-powered model uses a single sensor and PCB.

Power over Ethernet magnetometer installation. The sensor is buried for temperature stability but the electronics are contained in a separate box for space and cooling considerations.

A simple Raspberry Pi magnetometer

A simple Raspberry Pi magnetometer for indoor use can be constructed by connecting the standard sensor PCB(s) to a small interface board on the Raspberry Pi's GPIO interface. Single axis or 3-axis measurements are possible. The maximum distance between the interface board and sensor PCB(s) is limited to 2m. Construction and deployment is simplified at the cost of baseline variations caused by temperature dependence of the sensor(s) and greater human disturbances. In this configuration the magnetometer is functionally identical to the BGS schools magnetometers (see poster *Developing a network of school magnetometers for measuring space weather effects in the UK*) and is supported by the same data recording program.

## Data logging and visualisation software

The 3 magnetometer models described are supported with open-source Python software for data logging and control. Visualisation, processing and analysis is provided by an open source Python library, auroraplot, which can be installed with the standard pip installer.

Comparison with observatory magnetometers

The performance of the PoE model compares favourably with the BGS observatory grade magnetometers at Eskdalemuir and Hartland. The plot below shows Pi2 pulsations that preceded a magnetospheric substorm.
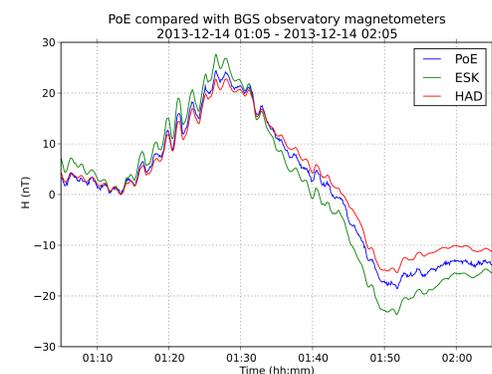
PoE magnetometer data recorded in rural garden location compared with observatory measurements.
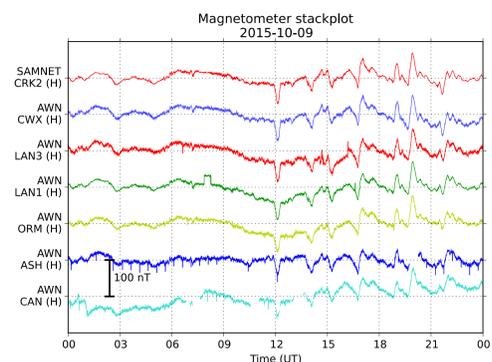
Stackplot generated by auroraplot, comparing the observatory-grade magnetometer at Crooktree (SAMNET CRK2) with low-power magnetometer stations. LAN1 is a PoE system, the other AWN magnetometers are battery-powered.

Further information

Data logging software and hardware design files for the battery-powered and Raspberry Pi models:

https://github.com/stevemarple/AuroraWatchNet/

Auroraplot library: https://github.com/stevemarple/auroraplot

Construction and operating manual:

http://aurorawatch.lancs.ac.uk/manual.pdf