Low-Cost Pulse Counting Networked Magnetometer

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Abstract

Building upon our previous successful low-cost (500 dollar) triaxial magnetometer design, we are developing a networked magnetometer (LCPCM), based on the Speake and Company FGM-3 fluxgate magnetic field sensor. A cluster of three sensors, each sensitive to magnetic variations as small as 1 nT, generate pulse streams non-linearly proportional to the strength of the surrounding magnetic field, and can measure a dynamic range of +/- 50,000 nT. A one second GPS timing pulse provides accurate time and position data, as well as a stable time base from which to calculate sensor frequency. The Microchip PICDEM.NET 2 Ethernet development board, based on the PIC 18F97J60 8-bit microcontroller, handles pulse counting and network communication. A PIC18F252 slave processor performs frequency measurement for the other two magnetic field components. Magnetic data are transmitted over the Internet or local area network to a data-logging server using the UDP protocol. Low cost, ease of use, and measurement accuracy makes this unit suitable for teaching as well as research.

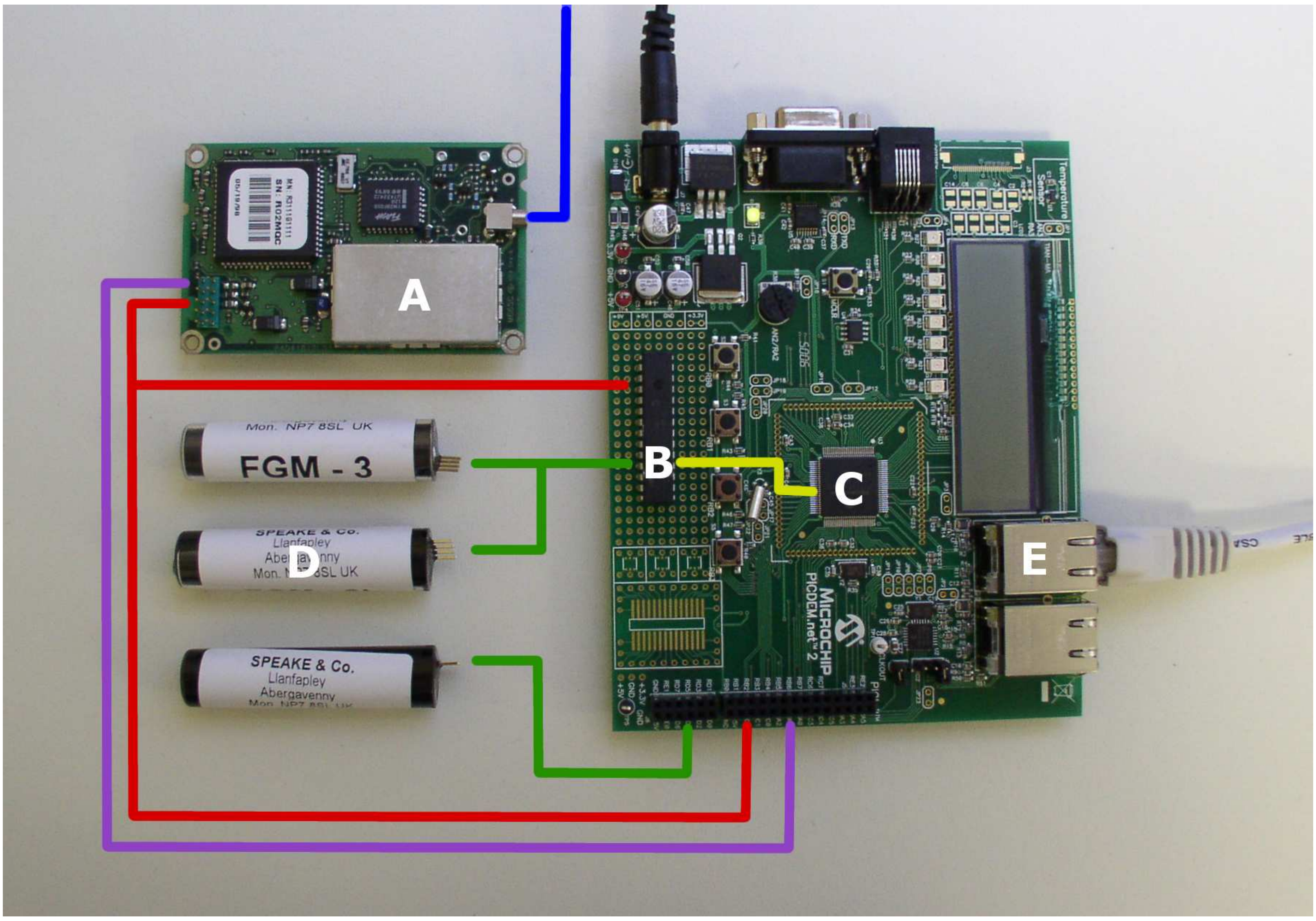


Figure 1: Illustrated block diagram of the LCPCM, based around the Microchip PICDEM.NET2 Ethernet development board (on the right). Motorola OnCore GPS engine generates precise 1-second time base for calculating pulse frequency from three pulse counting fluxgate magnetometers (D), each measuring X, Y and Z field components. PIC 18F96J60 microcontroller (C) coordinates data acquisition and communication. It also measures frequency from one sensor using an internal timer. Slave processor PIC 18F252 (B) measures other two components via internal timers. Main controller outputs time stamped data packet over Ethernet (E).

Technical Description

A Motorola OnCore GPS engine emits a precise 1 Hz pulse (red line), pictured in figure 1. This serves as the time base from which the pulse counting microcontrollers (B and C) calculate the pulse frequency. Microcontroller C (Microchip PIC18F97J60) is the primary controller, driving data acquisition, network communication, and frequency measurement of one of the 3 magnetic field components. Microcontrollers C and B are interconnected by a 4-wire serial peripheral interface link (SPI), shown in yellow. Microcontroller B (Microchip PIC18F242) slave processor measures frequency for the two remaining field components. Once microcontroller C reads date, time and location from the serial stream (in purple) from the GPS unit, it sends a time stamped UDP data packet over Ethernet link E (labeled E).

Three Speake FGM-3 pulse counting fluxgate magnetometer sensors (**www.speakesensors.com**) emit a TTL (0-5V) pulse signal that is non-linearly proportional to the magnitude of the local magnetic field. Each sensor measures the corresponding X, Y and Z field components, and is sensitive to magnetic variations as small as 1 nT. The pulse stream frequency falls in the tens of kilohertz. The green lines in figure 1 show the pulse stream flow from the PCM sensors to the two frequency-measuring microcontrollers (B and C). The PCM sensors are sensitive to temperature changes, so it is vital that they be situated in a stable temperature environment, such as underground.

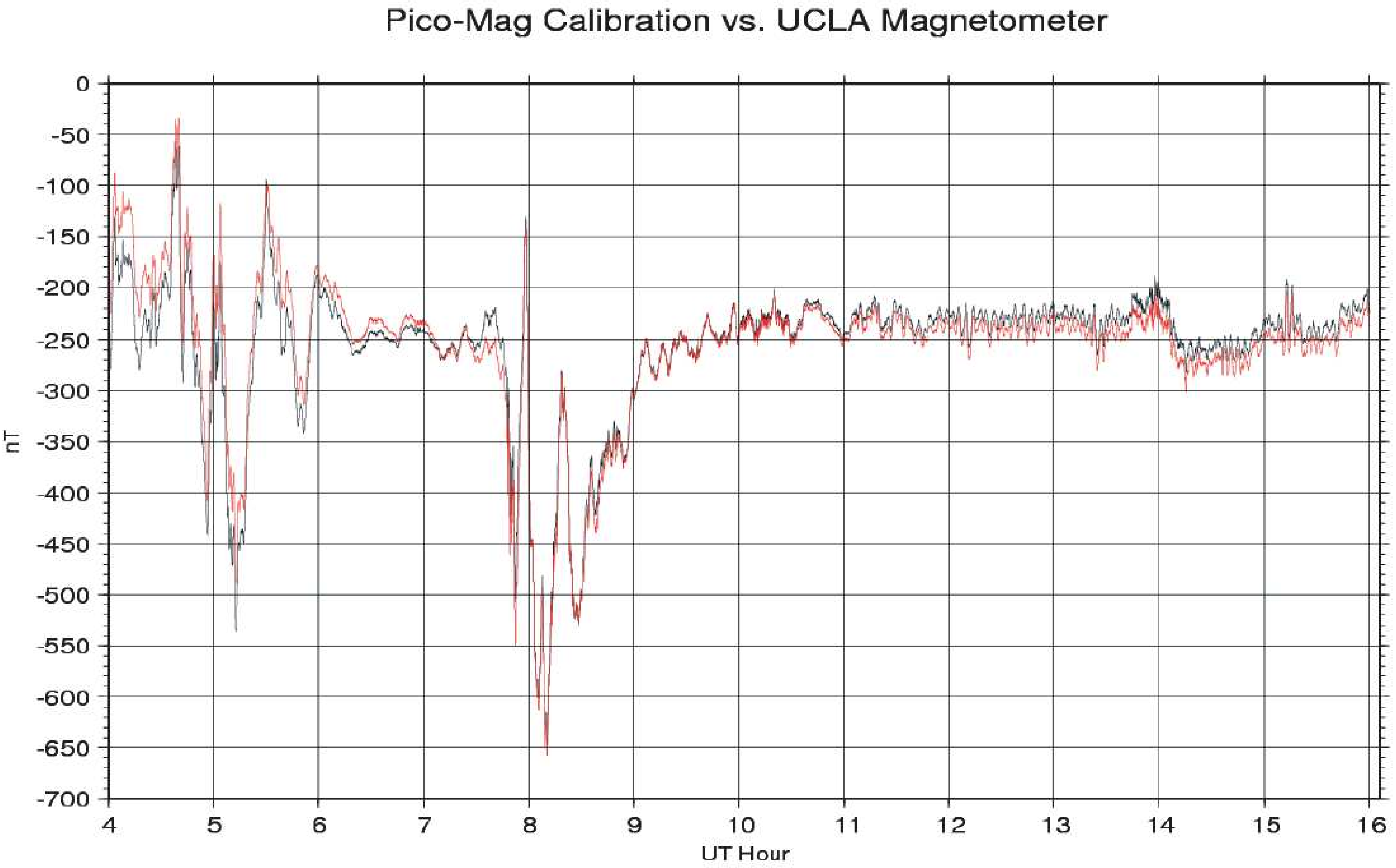


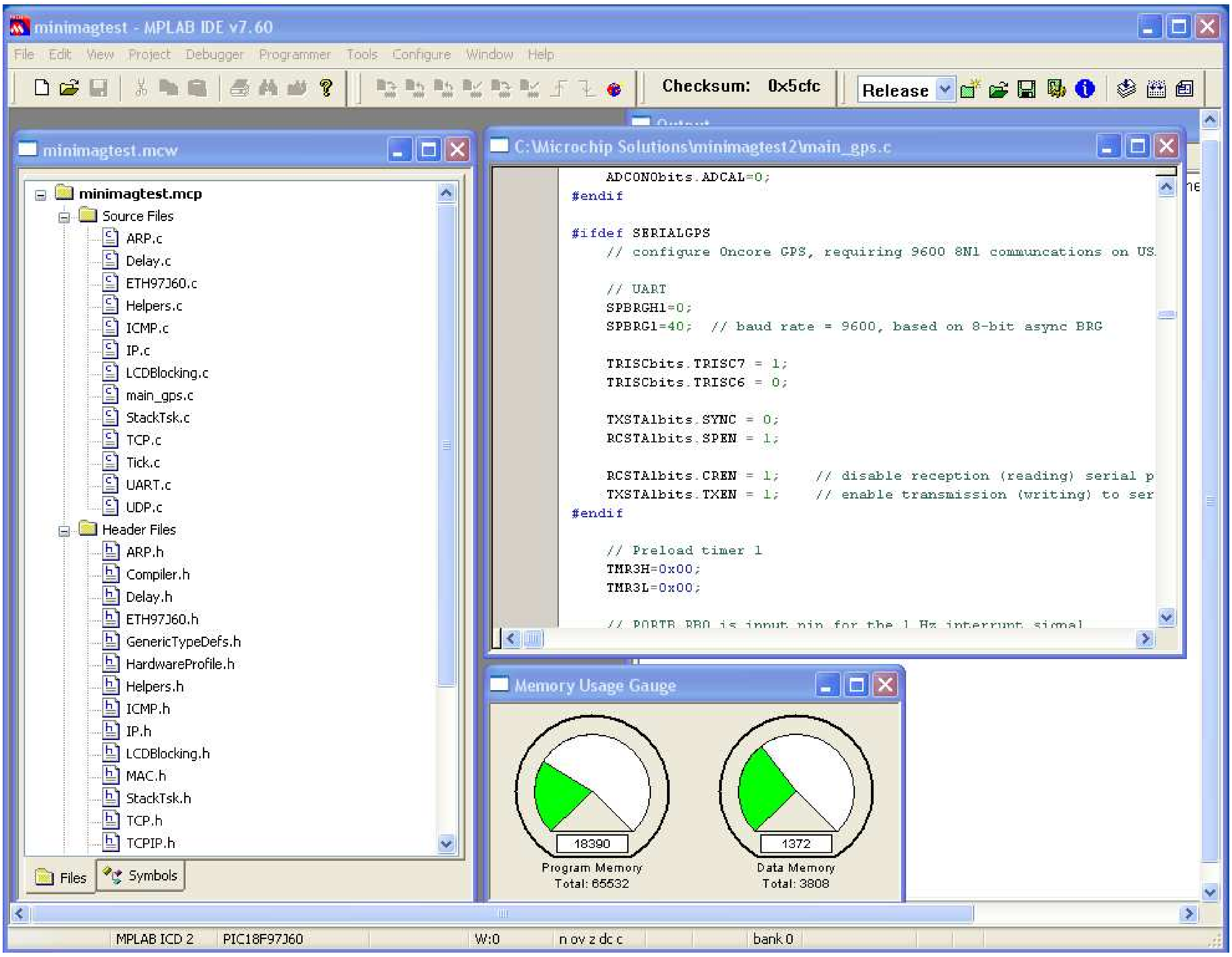
Figure 2: Y-component output from LCPCM (in red) compared to output from UCLA fluxgate magnetometer (black). Data taken March 10, 2004 at AUGO (Athabasca, Alberta).

Results

The graph shown in figure 2 shows close correlation of measurements between a known reliable research-grade magnetometer, a UCLA “small” fluxgate magnetometer, and the LCPCM (in red). Temperature calibration was performed on both measurements, based on temperature readings made at the observatory.

Software Development

With most embedded microcontroller systems, software executables are developed in a cross-compiler development environment. Typically, a Windows-based host compiles and links an executable binary image (*.hex file) that is uploaded into the target microcontroller's flash memory via USB serial link and a programmer. The Microchip MPLAB ICD 2 in-circuit debugger was used as the device programmer. This device loads the binary executable into the microcontroller's flash memory. The unit permits step-thru debugging and full-speed execution with support of a simulated text console, allowing use of print statements, which are useful for debugging.



```
    ADCON0bits.ADCAL=0;
#endif

#ifdef SERIALGPS
    // configure Oncore GPS, requiring 9600 8N1 communcations on US

    // UART
    SPBRGH1=0;
    SPBRG1=40;  // baud rate = 9600, based on 8-bit async BRG

    TRISCbits.TRISC7 = 1;
    TRISCbits.TRISC6 = 0;

    TXSTA1bits.SYNC = 0;
    RCSTA1bits.SPEN = 1;

    RCSTA1bits.CREN = 1;    // disable reception (reading) serial p
    TXSTA1bits.TXEN = 1;    // enable transmission (writing) to ser
#endif

    // Preload timer 1
    TMR3H=0x00;
    TMR3L=0x00;

    // PORTB RB0 is input pin for the 1 Hz interrupt signal
```

Figure 3: Screenshot of MPLAB IDE 7.60. The IDE includes an assembler that supports all Microchip PIC products, and can use optional Microchip compilers. Assembly/compilation, linking, debugging/simulation and programming can be performed from the IDE.

The LCPCM software is written in C using Microchip's MPLAB 7.60 integrated development environment in conjunction with the Microchip MPLAB 18C (version 3.12) C cross compiler. C18 is specifically targeted to the PIC18 family of devices, so the dialect of C used is mostly ANSI compliant, with special features that take into account the PIC 18's hardware limitations. TCP/IP functionality is provided by Microchip's TCP/IP Stack (version 4.02). The TCP/IP library includes routines for UDP (the mode of network transmission used by the LCPCM) and TCP sockets, plus high level protocols such as HTTP and FTP. The IDE, compiler and TCP/IP stack are freely downloadable as student versions, and are suitable for non-commercial development.

Applications

Due to the small number of magnetic observation stations scattered across northern Canada (figure 4), it is difficult to differentiate distant from proximal effects to the ground magnetic field. There are currently ~30 active magnetometer stations that are part of major observing networks operating across northern Canada. It would be advantageous to place more observatories in the auroral zone stretching across northern Canada between the 60 and 70 degree geomagnetic field lines.

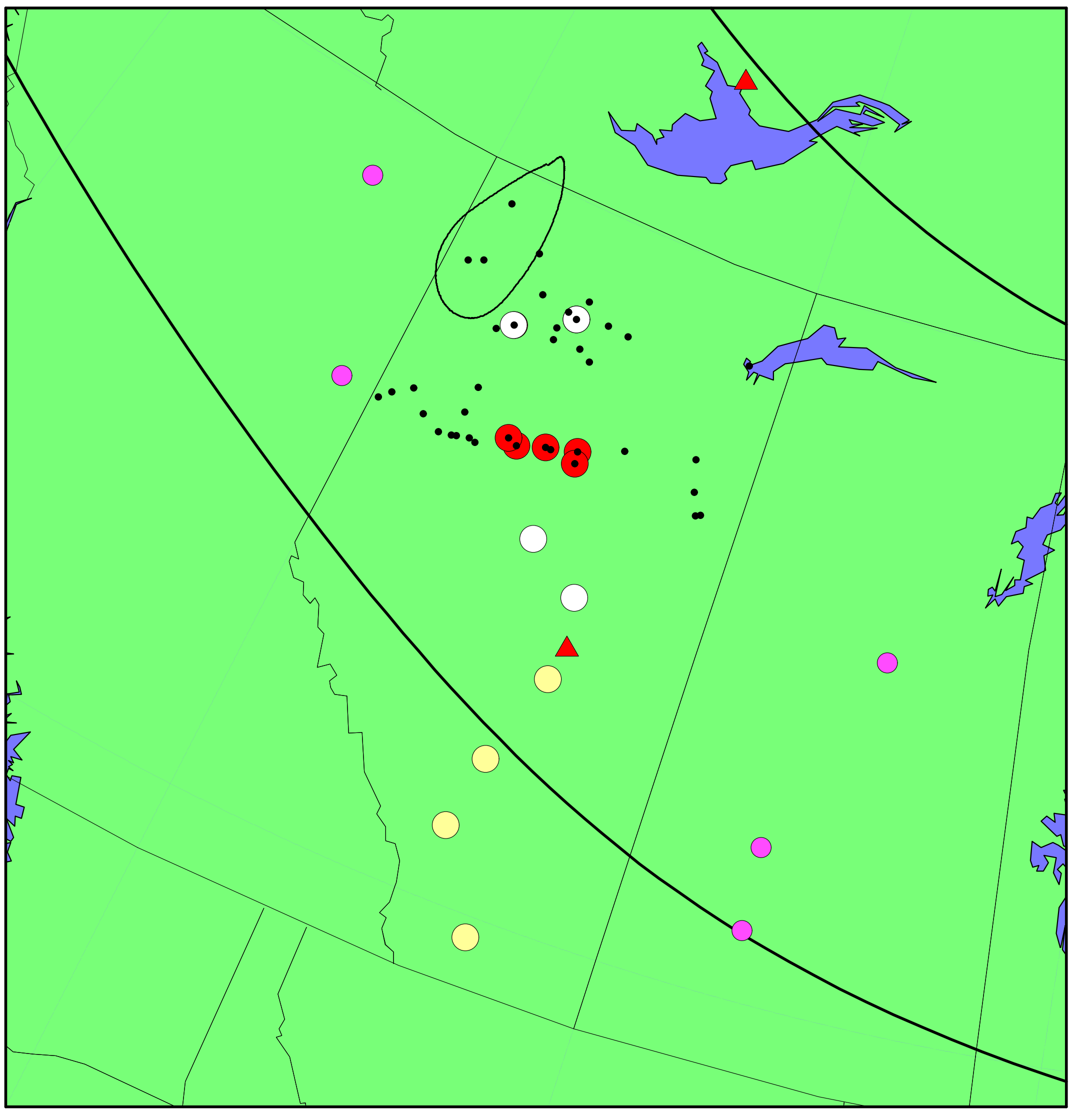


Figure 4: Above: currently operating and candidate magnetometer sites in northern Alberta. LCPCM stations could be installed at select Supernet sites (black dots) and Northern Lake College sites (red dots). Other networks include AUGO (white dots), CANMOS (red triangles), STEP (purple dots) and AUTUMN (yellow dots).

Figure 5: Anik F2 satellite footprint (white outline) showing coverage of Ka-band high speed satellite internet service.

The use of a network-enabled microcontroller-based platform at a time when availability of networking in remote locations is expanding, provides an unprecedented capability to monitor magnetic or other environmental data. Many sites in northern Alberta have broadband access via the Alberta government-sponsored 'Supernet'. In addition, Ka-band satellite Internet beamed from the Anik F2 satellite (figure 5) is available across all of northern Canada, reaching as far north as Baffin Island.

Conclusions

We have successfully migrated a low cost pulse counting magnetometer from a PC based design to one centered around an embedded 8-bit networked microcontroller board. Future refinements include integrating the PICDEM.NET 2 board with the GPS engine within a rugged housing, developing user-friendly data logging software, and developing interest among parties wishing to deploy the LCPCM.

Acknowledgements

Rob Irwin of Northern Lakes College has been a key partner in the Athabasca University Geophysical Observatory (AUGO) array placements including a test LCPCM. Measurements and calibration were performed by Ben Warrington, formerly of AUGO, and Ian Schofield, current AUGO observatory technician.