

Introduction

MAGLIN is a computer program designed to perform **continuous unattended data acquisition from one or more instruments**, with sampling rates typically between 0.01Hz and 800Hz. It has been originally created for geomagnetic observatories to acquire output signals of vector fluxgate and/or overhauser proton precession magnetometers (PPM) according to the INTERMAGNET standards. However, its configurable logging and data storage structure made it a general purpose data acquisition software. *MAGLIN* is written in C/C++ language using *Glib* library extensions. The *GTK+/gtkmm* multi-platform tool-kit is used for the graphical user interface. *MAGLIN* executables are available for Linux and Windows operating systems. *MAGLIN* is sold as part of *MAGREC-4* and *MAGREC-4B* computer or as accompanying software for *PalmAcq* acquisition module.

MAGLIN can be used on computers having limited resources, low power consumption and small capacity flash disk, like low-power x86 industrial computers or ARM based systems running Linux (like *Raspberry Pi*).

To be able to support the different recording requirements of different observatories and monitoring stations, *MAGLIN* uses a **modular sampling and data configuration** structure. This is achieved through the so called *Sampler* and *DataStore* software modules, where the number of the modules and the connection between the modules are flexibly adjustable. Each *Sampler* and *DataStore* have one or more *Components* (for example, X, Y and Z magnetic components). *Samplers* are responsible for communicating instruments and reading out their data into *components*. *DataStores* can convert, average/filter, store, save and plot the *components* data that are coming from *Samplers* or from other *DataStores*.

MAGLIN Samplers support data acquisition from the following data acquisition modules and instruments:

- Analog output instruments (like fluxgate magnetometers and analog sensors) through compatible A/D converters, and pulse output instruments (like fluid flow meters) through compatible pulse counter modules:
 - ADAM-4000 series acquisition modules (or compatible modules, such as ICP DAS I-7xxx series modules) through RS485 port,
 - *ObsDaq* A/D converter through RS485 port,
- LEMI-025 three-component observatory magnetometer with digital output,
- *GEM Systems'* GSM and *Quantum Magnetometry Laboratory's* POS-1 type overhauser magnetometers,
- DIDD (ΔIAD) magnetometer system with GSM-19 or GSM-90 magnetometer,
- Some instruments communicating through serial port using simple text protocol.

ADAM-4000 series modules are widely used in industry and science, as they are off-the-shelf products, commercially available in most countries. There are many different modules types, supporting analogue and digital inputs at one or more input channels. Analogue signals and RTD temperature signals can be acquired up-to 16-bit resolution. Maximum sampling rate is typically limited to about 1 Hz, if more

channels are sampled through the built-in multiplexed. If only one input channel is sampled, then sampling rate can go up to 10-16 Hz. Using digital input modules and pulse-counter modules, pulse-type signals can also be measured. ADAM modules are addressable, their address can be selected from 1 to 255. Using all addresses and RS485 repeaters, up to 255 modules can be chained in an RS485 network. Many data, even of different types can be collected through only one serial port by realizing an RS485 network with more connected modules.

ObsDaq is an A/D converter designed for fast readings from analog output magnetometers. It supports simultaneous three-channel high resolution conversion at higher sampling rates, and auxiliary 15-bit (10-bit in older versions) conversion for temperature/voltage monitoring at lower sampling rate. *ObsDaq* can optionally be triggered by GPS-PPS signal to get GPS-time synchronized recordings and time stamps with accuracy better than 0.1 ms.

Many instruments that outputs text messages on serial port can be attached to *MAGLIN*. Numerical data can be parsed out from the text messages using user-defined message format masks. The instrument should send the messages automatically at regular interval (like many digital output proton magnetometers in geomagnetic observatories), or the sampling can be triggered by text commands sent out at predefined interval by *MAGLIN*.

In the Linux version there is a possibility to incorporate other, non listed instruments, using Linux *FIFO* special files or Linux device files as text format communication channels between *MAGLIN* and the user created interface (driver) program.

If required, USB-to-RS232, USB-to-RS485, or RS232-to-RS485 port converters can be used to connect instruments and data acquisition units to the USB or serial port of the host PC. Surge protectors and/or fiberoptic cables should be used for longer connections because of surge risk of lightnings. In the ADAM-4000 series line, there are some industrial grade communication modules that can be used for these purposes (see *Appendix I*).

Some instruments like ADAM modules send out data in response to sample request commands, while other instruments, like *ObsDaq* A/D converters send out data continuously. In many configurations, *MAGLIN* uses the reception time of the first character of a record as time label for that record. User can define a time shift parameter to correct this time label to a slightly earlier time. For *ObsDaq*, *MAGLIN* can automatically determine this time shift. The accuracy of time label determination depends on some factors. The accuracy of time labels are within several millisecond or better if command triggered instrument (like ADAM modules' data) are sampled by *PalmAcq* module's or if data is sent at constant interval (e.g. *ObsDaq* free-run data) to an RS232 or RS485 port. If data are sent by an externally triggered *ObsDaq* A/D, then time labelling accuracy is much better than 1 millisecond. If data arrive directly through a serial or USB port of the computer, time labels' accuracy may depend on the computer's clock accuracy and on system load. For instruments that continuously output records at a regular, fixed interval, the time stamp adjusting feature of *MAGLIN* makes it possible to eliminate time stamp errors due to latency and program delays (at high system load), and time stamps with about ± 2.5 ms absolute accuracy (supposing PC clock is kept synchronized) are calculated. When using this

time stamp adjusting feature, the PC clock should continuously be adjusted by a GPS or network time synchronization software (such as *ntpd*), or by repeated manual adjustments.

MAGLIN can send out sample request commands to instruments based on computer's clock or *PalmAcq*'s GPS time. In the former case, timing accuracy of sample request command sending is 0.1-3 seconds relative of computer clock, depending on system load and CPU speed. The interval of command sending can be set from about 0.25 second to 1 hour, depending on the instrument's capabilities, the number of connected instruments and on the CPU speed. If sample request commands are sent by *PalmAcq*, then timing accuracy is much better: it is several millisecond, and up to 20 Hz command sending frequency can be programmed.

Some text output instruments can send accurate time information together with data (such as PPM magnetometers having built-in GPS). *MAGLIN* can use this time information to set the hour-minute-seconds of the PC clock.

PalmAcq real-time data acquisition module can be purchased as a separate module or as a built-in module in *MAGREC-4/MAGREC-4B* data acquisition computers. *PalmAcq* is designed to communicate one or more instruments through its RS232 and RS485 port. If used with *PalmAcq*, then instruments must use such a protocol where data records are terminated by carriage-return (decimal code: 13) or by line feed (decimal 10) plus carriage-return characters, and where data records does not contain NULL (decimal 0) character. *PalmAcq* recently supports data streams of up to about 400 Hz. *PalmAcq* has one RS232 or USB port for communicating to host PC, and has one RS232 port and one RS485 port to connect one or two instruments. *PalmAcq* incorporates a **GPS receiver** for timing and sample request command triggering. Once the GPS time has been determined (some minutes after power on), the GPS receiver can keep accurate time for the periods of poor satellite visibility. The PPS signal of the built-in GPS module makes the timing calculations very accurate. *PalmAcq* can be programmed to periodically send out sample request commands to the instrument. The command sending is synchronized to the PPS and the sending interval can be programmed up to 20 Hz speed. Some instruments have trigger input for sampling with controlled high timing accuracy. **PPS signal** from *PalmAcq* can be wired directly into such instruments and PPS can be used as a hardware trigger signal there. *ObsDaq* A/D converters have trigger input that can be used together with PPS output of *PalmAcq*.

The GPS time packets and GPS PPS signal events are used together to determine the accurate time labels of data received from the instrument(s). *MAGLIN* can plot, average/filter and save some GPS reported data from *PalmAcq*, similarly to other collected instruments' data. Such GPS data include coordinates, altitude, satellites in view and positional dilution of precision. External *PalmAcq* module can be connected to the host PC through USB or RS-232 port, while the sample timing accuracy is not influenced by the port's communication latency. *MAGLIN* keeps the PC's clock synchronized to the GPS time when used with *PalmAcq*.

MAGLIN's modular acquisition and data storage structure allows realizing **complex acquisition configurations**, from one or more instruments listed above. Raw data collected by *Samplers* are sent to *DataStores*, where they can be converted to final units using linear equations, and can be checked to fall within user

defined ranges. *DataStores* can also be connected together in many different ways and levels. *DataStores* can apply some filters to the values received from the *Samplers* or from other *DataStores*. The filtering interval and window can be selected by the user. It is possible to create second, minute, hour, day, etc. filtered values. Two standard filters, the arithmetic averaging function and the Gaussian filter are directly available. The special INTERMAGNET minute filter is also built-in to easily get standard minute magnetic data. It is possible to apply other, custom filters, whose coefficients are to be supplied in text data file. (A special filter for getting 1 Hz magnetic data from 128 Hz raw data is supplied with *MAGLIN* in this way.)

An other important configuration feature is that the components acquired from different instruments and/or components filtered in different manner can be mixed in *DataStores*.

Data records are saved on disk(s) and are put on plots in the graphical version of the program. For fast checking of sample timing accuracy, *MAGLIN* can calculate, plot and save time intervals between consecutive samples.

MAGLIN creates a list of **logs for different events and errors** (for example, for disk write errors, instrument communication problems and data out-of-range situations). This list is put on the screen and saved to disk as text format file(s). In case of continued or frequently repeated events/errors, *MAGLIN* tries to concatenate the events and to log only the starting and ending time of the events/errors to avoid long, repeating list.

Data and log files are saved at regular intervals. Saving interval can be selected between 2 and 60 minutes. Data files can be saved in **simple text format** or in **compact binary format files**. Saving into **IAGA-2002** format file and custom format ASCII files are also supported through a dynamically linked library file. A versatile command-line utility is provided to decompress compact binary files. File names and records' time labels in the text files are built up from the time stamps of the recordings. The user can set how to format the data file names and records time labels inside text files from the date/time. It is possible to create daily, monthly, yearly, etc. files by including or excluding day and month numbers in the file names. Data and log files can be saved to more locations with one or more file name masks and formats. For example, minute filtered magnetic X/Y/Z data can be saved to hard drive as daily text files and as monthly binary files, and at the same time, to a connected removable drive and/or network drive as minute binary files. Records in text files can be time labeled by the so-called Unix time (or POSIX time), which can make the data post-processing and data representation processes more easy.

MAGLIN's **scheduling function** can automatically execute any program, script, batch file after each data file saving cycle. In this way the system can be configured, for example, to automatically compress and send new data to an ftp server or to an e-mail account in every 2 minutes, using command-line ftp/email programs. *MAGLIN* can automatically call any program or script when selected data are going out of a predefined range. It is possible, for example, to configure the system to send e-mail alerts to the operator, or to implement custom temperature tempering by regulating heating/cooling elements when measured temperature get too low or too high.

The **graphical user interface** of *MAGLIN* allows easy and fast checking of the acquisition either on the site, or remotely, using remote access software. On the

program window the user can see:

- Some general information on the system (observatory name, instrument name, elapsed running time, current time),
- GPS time,
- Logs of different events and errors,
- Sent/received commands/responses between host PC and instruments,
- Latest acquired data and their changes,
- Short or long-term plots of acquired and filtered data.

There are **special features for safe unattended observatory operation**.

MAGLIN automatically deletes the oldest data files when disk space becomes too low, or when the number of files in the save directory goes above a limit. Computer software and hardware monitoring is also possible with *MAGLIN*. For example, memory usage, remaining disk space, CPU load and CPU temperature can be recorded, plotted and saved like regular data acquired from instruments, if appropriate measurement functions are supported by the hardware and the operating system. Alert schedules can automatically be started if some of these parameters are going out of a range. *MAGLIN* can handle the standard Linux watchdog device (“/dev/watchdog”), and the **two stage software/hardware watchdog** of the *MAGREC-4/MAGREC-4B* Linux computer. Using the scheduling function, it is possible to add custom watchdog functionality. (Watchdog’s task is to reboot the computer when the operating system or *MAGLIN* program stops working.)

The acquisition configuration (instruments, components, sampling rates, schedules. etc.) is defined in an “INI”-style **text configuration file**. Generally the software is shipped preconfigured for the user’s demand. However, the user can change the settings at any time by using the configuration program or by directly changing the INI file and then restarting the program. An easy graphical configuration program is also available for standard magnetic recording systems to help the user to change the most important settings.

Depending on the order and on intended utilization, *MAGLIN* is sold in different forms. Sold *MAGLIN* programs have some sort of copy protection. Some versions may have restriction on the computer it can be used on, on the featured instruments/program functions, and on allowed maximum number of components, *Samplers* and *DataStores*.

MAGLIN licence is generally sold as part of the *MAGREC-4/MAGREC-4B* computer system or as a software for external *PalmAcq* acquisition module. ***MAGREC-4B*** is a mini, fanless, low power Linux computer prepared for unattended data acquisition. It features flash system disk, hardware watchdog, 1x standard RS232, 2x standard RS232/RS485/RS422, 4x USB and VGA ports, a **middleweight Linux system** prepared for data acquisition. *MAGREC-4B* computers have *PalmAcq* electronics with GPS built-in the box. With *PalmAcq*, a special RS-232 and RS-485 port will be available, with GPS time based command triggering and time labeling functions.

MAGLIN might also be sold with external *PalmAcq* acquisition module. In this case the user has to supply the acquisition PC. The external *PalmAcq* module must be connected to the user’s Linux or Windows PC through RS232 or USB port.

Data acquisition from fluxgate and proton magnetometers through the *PalmAcq* module is the primary application of *MAGLIN* in geomagnetic observatories. In the typical configuration, triaxial fluxgate magnetometer components are sampled by ADAM-4017 (or ICP I-7017) 16-bit 8-channel A/D converter. The read-out is triggered at 1 Hz rate by the PPS GPS signal (see *Appendix-II* for an example). Using *ObsDaq A/D* instead of ADAM-4017, A/D sampling rates in about the 2.5 – 640.00 Hz range can be selected, and the effective A/D resolution is increased from 16-bits to about 17-23.5 bits (depending on the sampling rate and digital filtering). Sub-second magnetic data acquired by *ObsDaq* can be filtered to get one second data, using arithmetic averaging or standard Gaussian filter (defined by the standard deviation parameter), or user's custom filter. By filtering or averaging, the effective resolution of one second data will be higher than effective resolution of sub-second data. INTERMAGNET minute filter can be applied for the one second magnetic data to get minute means. The fluxgate and/or proton magnetometer recording system can be extended with auxiliary signal recoding at 1 Hz or lower frequencies. Typically, magnetometer's temperature and supply voltage data are recorded together with magnetic data. The auxiliary signals can be digitized on the free input channels of the *ObsDaq* or ADAM-4017 modules. The user can extend the system by connecting additional ADAM analog or digital input module(s) to RS485 line, to get additional temperature, voltage, digital-input or frequency recordings. *MAGLIN* can read **DIDD** ($\Delta I \Delta D$) magnetometer data and calculate magnetic components from its deflected values.

The following schematic figure represents the typical instruments and their connections of an observatory recording system with fluxgate and proton magnetometers, with *MAGREC-4B* computer having integrated *PalmAcq* electronics and Linux operating system and *MAGLIN* program.

