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A new software for the measurement of magnetic moments using SQUID and spinner magnetometers ☆

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ABSTRACT

A new software package, called *CryoMag*, facilitates the measurement of magnetic moments using both 3-component (i.e. Superconducting QUantum Interference Device) and 2-component (i.e. spinner) magnetometers. The measurement process is optimized for, but not limited to, stepwise demagnetization experiments commonly used in paleomagnetism. A graphical representation of the data is always visible to the user in the form of orthogonal, stereonet and decay diagrams, which can be represented in in situ, geographic or tilt corrected coordinates and can be saved as graphics files. Instrument specific settings, as well as arbitrary measurement positions, can be easily customized in a single configuration file. A comprehensive record of detailed measurement and statistical data is stored in XML (eXtensible Markup Language) based data files (∗.cmag.xml). The final results of the measurements can be exported to several common file formats for further processing. The software is written in *Python*, an open source, cross-platform programming language and can therefore be used on popular operating systems like Windows, Linux and MacOS X. The complete source code is available on request from the author. The CryoMag open-source allows anyone to adapt the software to their specific equipment, file format and experimental requirements.

1. Introduction

Consecutive measurement of magnetic moments of oriented rock specimens is the fundamental method of typical paleomagnetic studies (e.g. Butler, 1992; McElhinny and McFadden, 2000). Such data allow one to study the paleo-movement of the continents, the long-term behavior of the geomagnetic field, magnetostratigraphy, paleointensity, paleocurrent, etc.

Due to the large amount of data, it is crucial to carry out the measurements as efficiently as possible. Besides having adequate instrumentation, the operating software can have considerable bearing on the quality of the measurements. Although no software program can improve the fundamental measurements, it can aid the operator to choose the next (de)magnetization step and to recognize potential inconsistencies by providing statistical parameters and visualization of the data during the measurement process. The possibility to review raw data quickly and efficiently allows one to recognize potential error sources and to correct for them, and assists the interpretation process.

At present, there are two ways paleomagnetists operate their magnetometers: either they obtain a software package from the company that sold the magnetometer, or they write the software themselves. Commercial software is mostly limited to the Windows operating system and to a single, specific instrument. No customization can occur, as source codes remain proprietary. Molspin Ltd[1] and AGICO Inc.[2] offer software packages free of charge (spin4d and REMA5/REMA6, respectively) to operate their contemporary spinner magnetometers. 2G Enterprises[3] sells different software packages, starting at a price of $2500, to operate their SQUID magnetometers. For older versions of instruments (e.g. AGICO, JR-4 spinner magnetometer) no modern, adaptable software package exist, unless one obtains a copy from a generous colleague. There are free software packages specific to custom-built, automated setups for magnetometers (Giddings et al., 1997; Frederichs et al., 2000; Kirschvink et al., 2008; Morris et al., 2009) and u channel measurements (e.g. Xuan and Channell, 2009), but there is neither a ready-to-use downloadable package nor a publication that provides the source code for the several-hundred paleomagnetic laboratories worldwide. CryoMag was written to fill these voids.

CryoMag is a new, user-friendly software package with a graphical interface, based on the cross-platform wxWidgets library (Smart et al., 2010), to carry out remanent magnetization

☆ Code available from server at http://www.geophysik.uni-muenchen.de/Members/wack/software.

E-mail address: wack@geophysik.uni-muenchen.de
URL: http://www.geophysik.uni-muenchen.de/Members/wack

[1] Molspin Ltd Website, http://www.molspin.com/
[2] AGICO Inc. Website, http://www.agico.com/
[3] 2G Enterprises Website, http://www.2genterprises.com/

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measurements on SQUID or spinner magnetometers. It provides an intuitive handling and presents all relevant data at a glance, thus allowing the user to focus on the measurement itself and not on the operation of the software. *CryoMag* is written in *Python* (van Rossum and Drake, 2009) an open source, cross-platform programming language. *CryoMag* runs on most computer systems, operates different types of magnetometers with a consistent user interface, and generates multiple file formats and data graphics, which eases everyday workflow and enables efficient use of existing hardware. Below is a description of *CryoMag* for SQUID systems.

2. Measurement process and user interface

After sample preparation, typical paleomagnetic demagnetization experiments begin with measuring the magnetization of the sample holder, so that it can be subtracted from subsequent measurements of the specimens. Then the natural remanent magnetization (NRM) is measured for all specimens. Subsequently the specimens are progressively demagnetized using alternating magnetic fields (AF) or thermal heating (TH), and after each treatment their magnetic moment is measured. The number and spacing of demagnetization levels is up to the operator. Specimens are measured several times in different orientations to improve the accuracy by averaging and to get an estimate of the scatter in terms of standard deviation of the total moment and the half angle of the 95% confidence cone (a 95) of the magnetic vector direction.

The main functions of the program are organized in a panel that is displayed in the upper right half of the main window (Fig. 1A). Different functions and the corresponding panels can be activated by the row of buttons located below the active panel (Fig. 1B). The rest of the main window contains three diagrams (Fig. 1C–E) which are discussed in Section 2.5. In the following sections the various options and functions are described in the order of a typical workflow for 3-component SQUID magnetometers, yet most functions and displays are similar for spinner magnetometers.

2.1. Settings

All settings are reset to reasonable default values at program startup and can be modified by the user for their needs (Fig. 2). Some fundamental settings that should not be changed during regular use can only be modified by editing a configuration file called *CryoMagSettings.py*. These include the definition of the different sets of measurement positions, the calibration factors of the sensors, the type of instrumentation and the number of averaged readings per measurement. To avoid unwanted changes to critical parameters the configuration file can be write protected via the operating system.

2.1.1. Holder positions

Holder measurements can be carried out in two ways. The default is to measure the holder in four positions, each time turned by 90% about the (vertical) z-axis of the magnetometer (counterclockwise seen from above). The other option is to measure the holder four times in the same position.

2.1.2. Specimen positions

Different measurement schemes, consisting of several predefined measurement positions, can be selected. Measurement positions are defined by three Euler angles. The rotation is given by three angles A, B, C, where the first rotation is by an angle A about the specimen's z-axis (z in Fig. 3), the second is by an angle B about the specimen's (rotated) x-axis (x^1), and the third is by an angle C about the specimen's (rotated) z-axis (z^2) (Czichos, 1996). Internally, the rotations are performed using the following rotary matrices:

$$\check{M} = \begin{pmatrix} c_A & -s_A & 0 \\ s_A & c_A & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_B & -s_B \\ 0 & s_B & c_B \end{pmatrix} \cdot \begin{pmatrix} c_C & -s_C & 0 \\ s_C & c_C & 0 \\ 0 & 0 & 1 \end{pmatrix}$$
$$= \begin{pmatrix} c_A c_C - c_B s_A s_C & -c_B c_C s_A - c_A s_C & s_A s_B \\ c_C s_A + c_A c_B s_C & c_A c_B c_C - s_A s_C & -c_A s_B \\ s_B s_C & c_C s_B & c_B \end{pmatrix}$$
with $c_X = \cos X;\ s_X = \sin X$

The standard position (all angles equal to zero) means that the axes of the specimen are aligned with those of the magnetometer which should be chosen according to the arrangement of the SQUID sensors and the user's conventions.

2.1.3. Baseline

Since SQUID sensors can only measure relative changes of magnetic fields, a zero-point has to be defined. This is done by reading the sensor's baseline without any specimen present. Subsequent measurements of specimens are always corrected for this baseline value. To overcome potential instrumental drift, it is advisable to measure baselines as often as possible. Cryomag provides the possibility to measure baselines before and after the measurement of all positions of one specimen or before each individual position. The user can specify a warning threshold in the lower part of the settings panel. If the difference between two subsequent baselines during the measurement of a specimen is greater than the chosen warning threshold (Fig. 2, bottom), a message will be displayed.

2.2. Measurement

Measurement of the holder or specimen can be started by selecting 'Holder' or 'Measurement' from the button row. The measurement itself works in a very similar way for holders and specimens. In the case of a specimen, before each step, a specimen name, a step value and type and optionally a comment must be supplied in the corresponding edit fields (Fig. 4). Pressing Enter on any field accepts the default or modified value and moves the cursor to the next field. Pressing Enter in the comment field activates the first measurement as specified earlier by the user in the settings panel. A short status message and the properties of the current specimen are shown in the upper part of the measurement panel. Each measurement can be executed by pressing Enter. In this case, the x-, y- and z-components of the magnetic moment is read several times (by default three times; defined in the configuration file, see Section 2.1) from the magnetometer and averaged. Then the values of the most recent baseline and of the holder are subtracted and the resulting vector is written to the screen after accounting for the Euler angles which define the orientation of the specimen (see Section 2.1.1). The results are filled in the appropriate columns in the measurement list (i.e. x-, y- and z-components of magnetic moment, total moment, standard deviation of the total moment, half angle of 95% confidence cone a 95 (Butler, 1992), inclination and declination in core coordinates). The standard deviation and a 95 are based on the variation of the repeat readings of the magnetometer (the default is 3, but the user can change this in the settings panel). All completed measurements can be repeated by pressing the corresponding number key on the keyboard.