MinGeo Ltd.

Operation Manual of FluxSet Declination/Inclination Magnetometer

László Hegymegi, Csaba Hegymegi and Ádám Domján

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Contents

1 Introduction

The magnetic field on the Earth is changing in time and space. The geomagnetic field is a vector field which can be given by three coordinates depending on the reference system. The quantities used to describe the magnetic field are defined with respect to the geographic coordinate system (figure 1). The declination D is the angle between the true North and geomagnetic North, positive to the East. The inclination I is the angle which the magnetic vector makes to the horizontal plane. The total field F is the magnitude of the field vector. Other widely used magnetic components are horizontal intensity (H – the projection of the field vector to the horizontal plane), vertical intensity (Z – the vertical component of the field), north component (X – component pointing to the true north in the horizontal plane), East component (Y – component pointing to the east in the horizontal plane). The international standard for global distribution of normal values of magnetic field is published by the IAGA every five years. It is called the International Geomagnetic Reference Field (IGRF). For the IGRF 2005 D, and I values, see the Appendix.

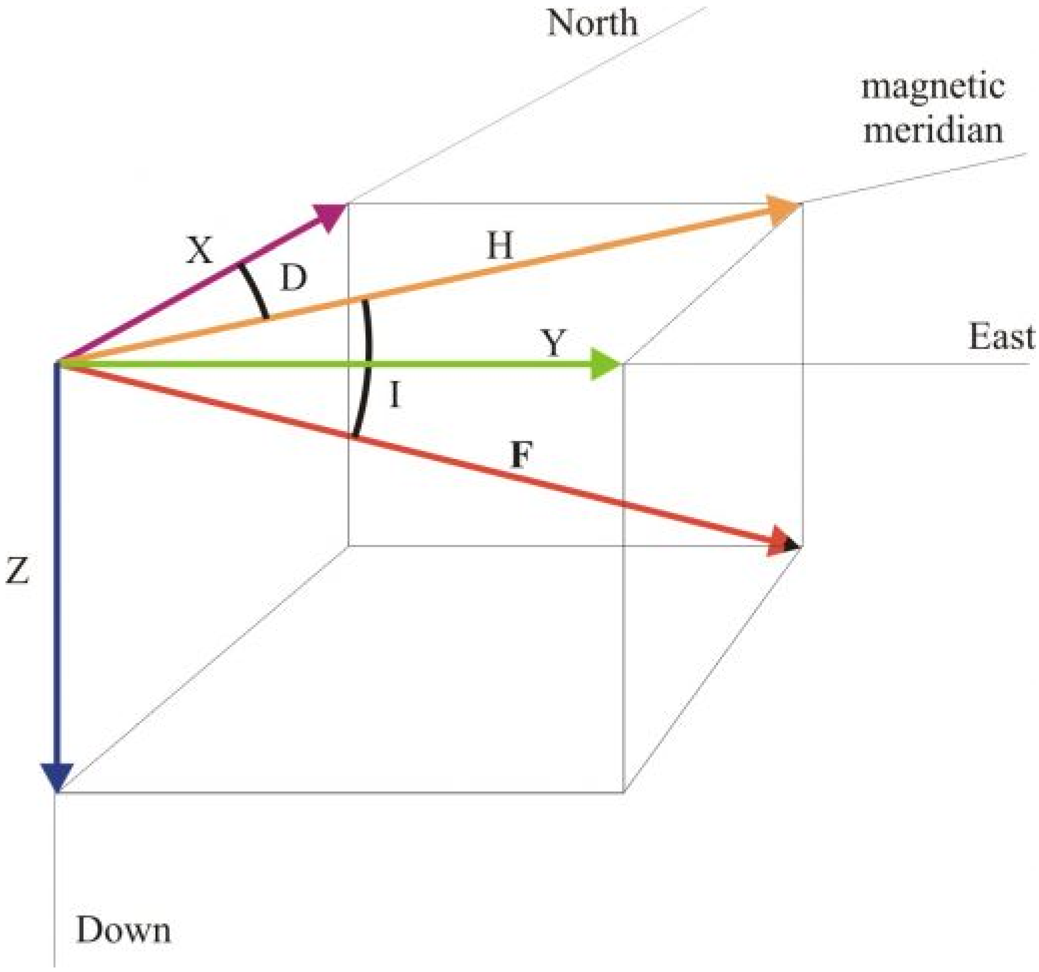

Figure 1: The components of the Magnetic Field Vector

2 FluxSet Declination/Inclination Magnetometer

This manual describes how the MinGeo FluxSet Declination/Inclination Magnetometer (DIM) can be used for measurements of the magnetic field. The DIM itself is suitable for determining the direction, i.e. the Declination D and the Inclination I of the field vector only, but not its magnitude. The properly used DIM gives the mean absolute value of D and I for the observing period with a small error. Combined with a total field instrument (proton precession magnetometer, Overhauser magnetometer, optically pumped magnetometer, etc.) the DIM is capable to describe all magnetic elements.

The DIM consists of a steel free ZEISS 10/15/20 theodolite (figure 2) and a one axis FluxSet magnetometer (Type FXM-T101) mounted on its telescope. A large-screen android tablet and a small radio unit with a micro USB port are included in the package of DIM equipment. In the tablet there is an android application named by *DIM*, which is designed to facilitate the absolute magnetic measurement.

Figure 2: FluxSet Declination/Inclination Magnetometer components

The theodolites are transformed steel-free from commercially available geodetic theodolites. During this cleaning process all elements are checked magnetically and any part contaminated is removed and replaced for components made of non-magnetic material. The extremely magnet free device (everywhere less than 1 nT at 1 cm distance from the surface of the instrument) makes it possible to carry out precise measurements. The high sensitivity FluxSet magnetometer yield 0.1 nT resolution field reading. The offset of the electronics is set to less than ± 10 nT. The magnetic axis of the sensor fixed on the theodolite is carefully adjusted to the optical axis of the telescope within some tens of arc seconds.

This manual gives procedures for absolute measurement, describe the use and maintenance of the DIM instrument, including the readjustment of the sensor and the electronics offset. For more details on the use of the theodolite see the cited Zeiss Manual (hereafter ZM).

3 Preparation for an absolute measurement

In observatory practice the purpose of absolute measurements is to determine the baseline of magnetic variometers. The measurements are taken on the absolute pier of the observatory. The absolute pier and its surrounding, as the instrument itself, are supposed to be free of any magnetic contamination. Care must be taken to avoid any influence from magnetic objects during the measurement procedure.

The observer himself also has to be clean magnetically, magnetic glasses, pens, watches must be removed from the vicinity of the DIM. The safety distance for every object should be determined by the measurement of its magnetic influence. Also the observer should check his magnetic hygiene before every measurement. This can be done in any null position (see later) of the sensor. The distance where the object (observer) has an influence less than 0.2 nT may be accepted as a safe distance. The accuracy of the absolute measurement depends even on the disturbance level (the time derivative) of the field. Measurements taken during highly disturbed, stormy periods can lead unacceptable results.

For the determination of the declination in addition to measurements made by the DIM, a reference direction is needed. The easiest way is to use a reference mark (also called azimuth mark A_z). It is necessary to know the azimuth of this mark (viewing from the absolute pier) with an accuracy of 1 arc second in an observatory and 0.1 arc minute in the field. The horizontal error of the positioning of the theodolite above the pier mark and the distance of the reference mark influences the accuracy of the declination. In the field where no piers are available, a non-magnetic tripod must be used. The procedure of installing the DIM on a tripod is described in

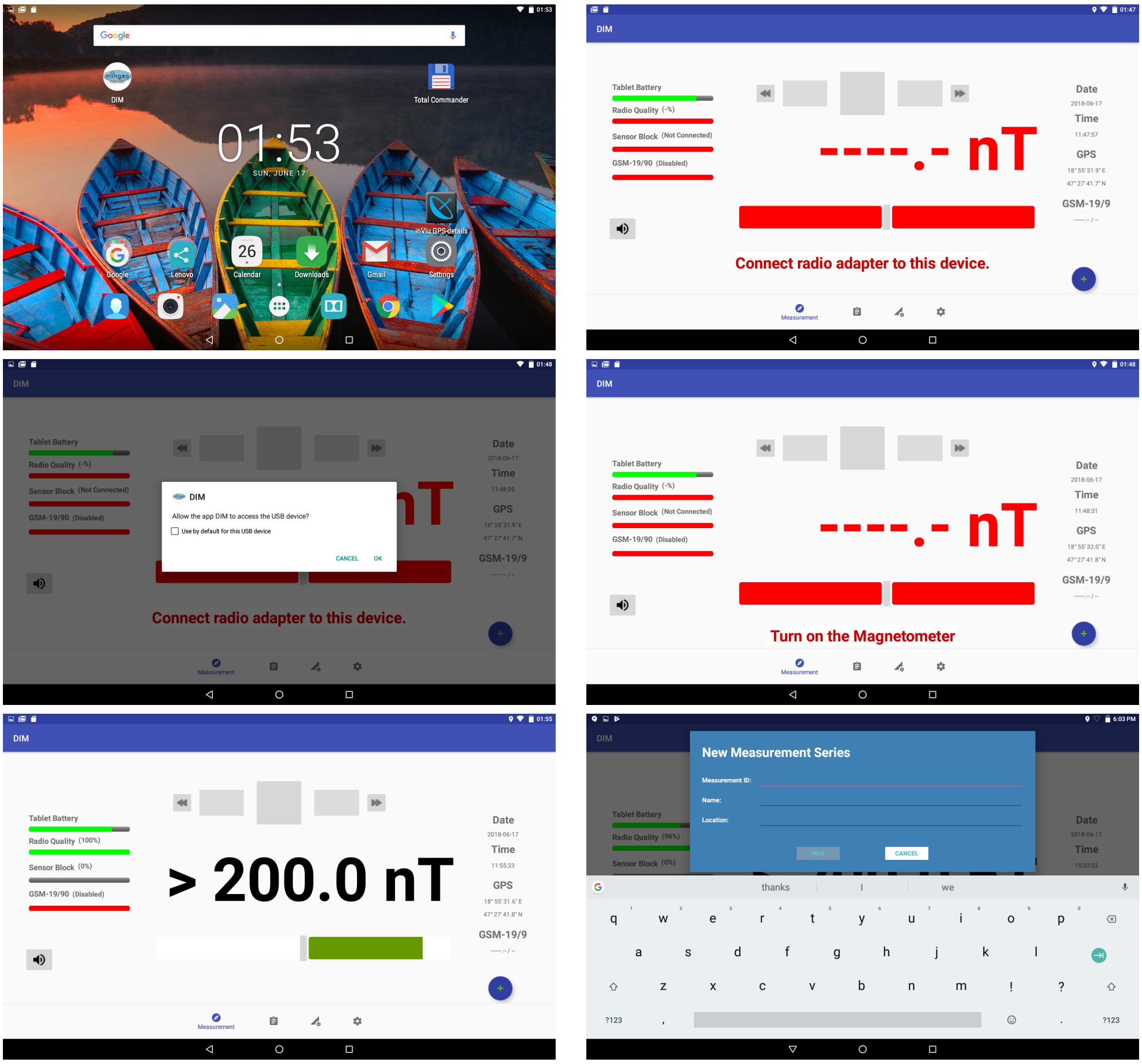

Figure 3: Screenshots of DIM application

section 4.1 - 4.3 of ZM.

4 Absolute measurement process

4.1 Null method

In the following section the procedure of absolute measurement according to the null method will be given. It is supposed that the observer has some basic knowledge and skill in handling the theodolite, such as setting up the theodolite (ZM 4.1-4.2), leveling (ZM 4.3), adjusting the horizontal circle to reference azimuth (ZM 4.8), reading the horizontal and vertical circles (ZM 4.7), setting the horizontal or vertical circle to a given angle.

As the mechanical axes of the theodolite, the optical axis of the telescope and the magnetic axis of the FluxSet sensor always have some misalignment error, moreover, the theodolite may have further mechanical errors (collimation errors, non orthogonality errors of the horizontal and vertical axis etc.), and as the offset of the electronics is not zero, the declination/inclination of the field can not be determined from a single reading of the horizontal/vertical circle. However, most of these errors are eliminated by the measuring process, using four position readings for each element.

1. **Leveling**
   Level the theodolite (ZM 4.3) already set up on the pier / on the tripod.

2. **Software initialization**
   Place the tablet on an easy-to-see free pier / spot at least 2 m away from the leveled theodolite. Turn on the tablet.

2.1. **DIM application**
Run the DIM application (figure 3a). As you can see on main page of DIM (figure 3b), plug the radio unit into the tablet's micro USB port. Press OK for the pop-up window (figure 3c). Turn on the FluxSet magnetometer on the telescope to establish connection between them (figure 3d). If the radio connection is successful then you will see sensor's output in the middle of the display (figure 3e).

2.2. **Create a new file**
For creating a new absolute magnetic measurement file, press the icon in the bottom left corner (figure 3e). Fill the cells with your desired input (figure 3f).

2.3. **Select a measurement sequence**
Click the icon in the bottom of the display (figure 3e). Make sure the null method is selected (figure 4a). Go to the measurement template (figure 4b). Click again the saved measurement template. Select your type (figure 4c). The next sensor position will be displayed according to the selected template on main page of *DIM*.

2.4. **Create a new measurement sequence**
Go inside the profile manager (figure 4b). Here you can customize a your sequence (figure 4d and 4e). When you saved it, click again the measurement template, then you can select it among the others (figure 4b and 4f).

2.5. **Other options**
You can select the acoustic help in the sensor settings (figure 5a). For modifying the the angle unit, time format, GPS format and scalar magnetometer settings on the *DIM*s main page (figure 3e) select the icon in the bottom of the display (figure 3e).

3. **Adjustment of the horizontal circle**
Adjustment of the horizontal circle to the reference azimuth A_z (ZM 4.8.) can be done in different ways. This step is rather advised, than necessary. The goal of this step is to make the readings and calculations more comfortable, since in this case the horizontal readings taken during the observation of D will be close to the value:

$$D + n \cdot 90^\circ \quad \text{where} \quad n = -4, -3, \cdots + 4 \tag{1}$$

Here the actual values of n depend on the declination and the difference between the azimuth and the horizontal reading of azimuth mark. This latter difference can be chosen to 0 (as in ZM 4.8), or $k \cdot 90^\circ$ $k = \pm 1$. Following the Hungarian standard procedure we will use a -90° difference for the first position. Turn the telescope to have the sensor on the top (up position). With the telescope pointing to the azimuth mark, adjust the horizontal circle approximately to $A_z - 90^\circ$. If $A_z - 90^\circ < 0^\circ$, add 360°.

4. **Observation of Declination**

4.1. **Measurement of mark sighting in the 'sensor up position'**
Point the telescope to the azimuth mark (sensor up). Read the horizontal circle. Press the left button on the remote controller. Type the horizontal angle value in the MU (Mark up) pop-up window of the display (figure 6a).

4.2. **Measurement of mark sighting in the 'sensor down position'**
Invert the telescope to have the sensor on the bottom (sensor down position). Point the telescope to the azimuth mark. Read the horizontal circle. Press the left button on the remote controller. Type the horizontal angle value in the MD (Mark down) pop-up window of the display.

4.3. **Position East up**
Reverse back the telescope to have the sensor up again. Set the vertical index to exactly 90° (telescope horizontal). Rotate the alidade so that the telescope points roughly to the East. Fine adjust the alidade slowly searching for the null position (null reading on the display of the tablet). A value ± 0.1 nT can be accepted. Read the horizontal circle. Press the left button on the remote controller. Type the horizontal angle value in the *EU* (East up) pop-up window of the display. The Universal Time (from the built in tablet GPS) t_{EU}, magnetometer output will be saved by the application in the data table.

4.4. **Position West up**
Rotate the alidade with approximately 180° so that the telescope points roughly to the West. Fine adjust the alidade slowly searching for the null position. Read the horizontal circle. Press the

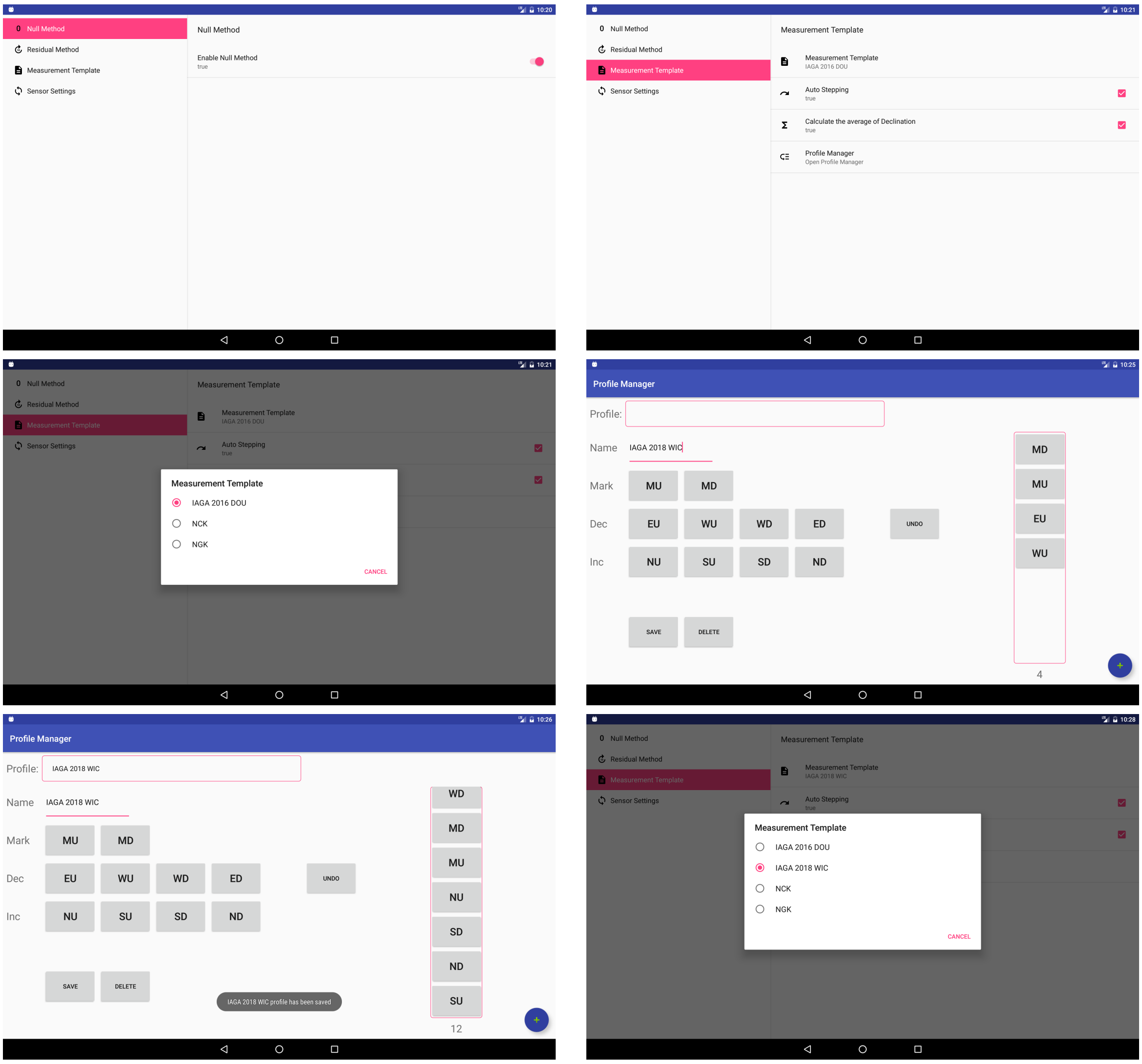

Figure 4: Screenshots of DIM application

left button on the remote controller. Type the horizontal angle value in the WU (West up) pop-up window of the display. The Universal Time t_{WU}, magnetometer output will be saved by the application in the data table.

4.5. **Position East down**

Turn the telescope to have the sensor down. Set the vertical index to exactly 270° (telescope horizontal). Now the telescope points roughly to the East. Fine adjust the alidade slowly searching for the null position. Read the horizontal circle. Press the left button on the remote controller. Type the horizontal angle value in the ED (East down) pop-up window of the display. The Universal Time t_{ED}, magnetometer output will be saved by the application in the data table.

4.6. **Position West down**

Rotate the alidade so that the telescope points roughly to the West. Fine adjust the alidade slowly searching for the null position. Register the time at the moment of null reading t_{WD}. Read the horizontal circle. Press the left button on the remote controller. Type the horizontal angle value in the WD (West down) pop-up window of the display. The Universal Time t_{WD}, magnetometer output will be saved by the application in the data table.

4.7. **Calculation of A**

The application will calculate the mean of the four horizontal circle readings:

$$A = {}^{1}\!/_{4} \cdot (EU + WU + ED + WD) + m \cdot 90° \qquad (2)$$

where $m = \pm 1$ for east/west declination. A is the angle of the magnetic meridian (MM) in the theodolite reference frame (slightly differing from the azimuth of the MM).

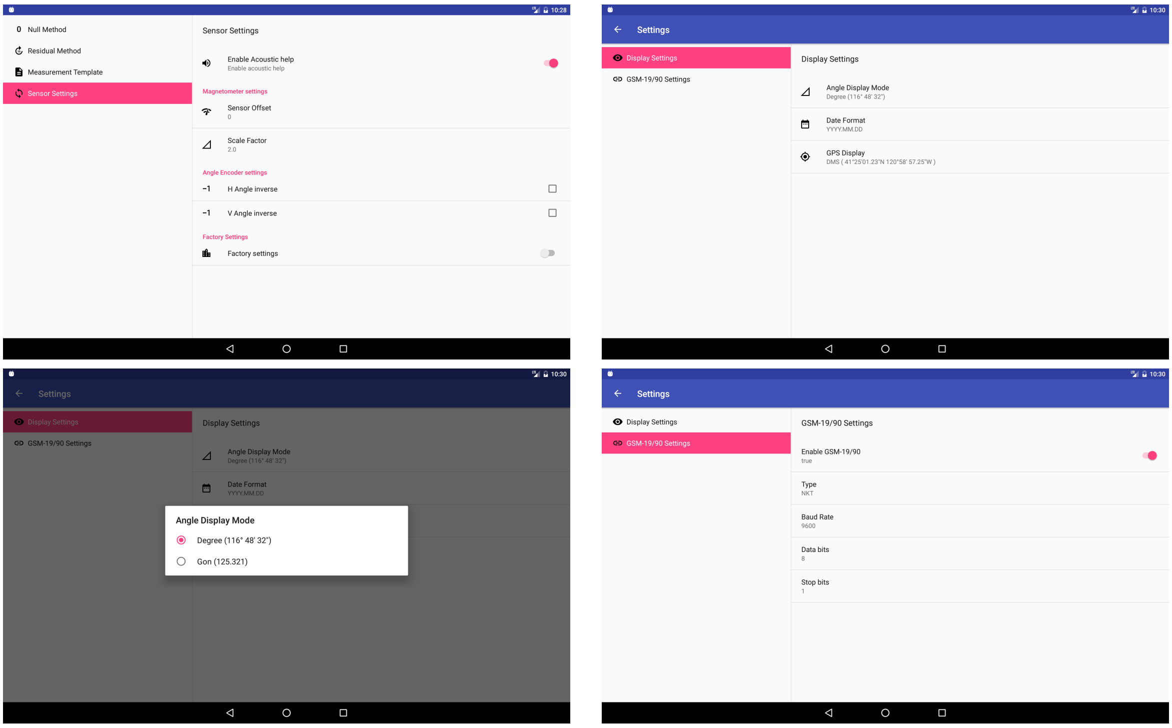

Figure 5: Screenshots of DIM application

5. Observation of Inclination

5.1. Position North up

Reverse back the telescope to have the sensor up again. Rotating the alidade set the horizontal circle to exactly $A + 270°$ (telescope in the meridional plane). Turn the telescope to point roughly to the North. Fine adjust the telescope slowly searching for the null position. Read the vertical circle and the momentary total field F_{NU}. Press the left button on the remote controller. Type these values into the NU (North up) pop-up window of the display. The Universal Time t_{NU}, magnetometer output will be saved by the application in the data table.

5.2. Position South down

Turn the telescope to point roughly to the South. Fine adjust the telescope slowly searching for the null position. A value +/-0.1 nT can be accepted. Read the vertical circle and the momentary total field F_{SD}. Press the left button on the remote controller. Type these values into the SD (South down) pop-up window of the display. The Universal Time t_{SD}, magnetometer output will be saved by the application in the data table.

5.3. Position North down

Rotate the alidade with exactly 180° to (A+90°, telescope in the meridional plane). Turn the telescope to point the telescope roughly to the North. Fine adjust the telescope slowly searching for the null position. Read the vertical circle and the momentary total field F_{ND}. Press the left button on the remote controller. Type these values into the ND (North down) pop-up window of the display. The Universal Time t_{ND}, magnetometer output will be saved by the application in the data table.

5.4. Position South up

Turn the telescope to point roughly to the South. Fine adjust the telescope slowly searching for the null position. Read the vertical circle and the momentary total field F_{SU}. Press the left button on the remote controller. Type these values into the SU (South up) pop-up window of the display. The Universal Time t_{SU}, magnetometer output will be saved by the application in the data table.

6. Useful information

If more set is taken the whole procedure must be repeated from the beginning. For setting the theodolite the appropriate direction see figure 7.

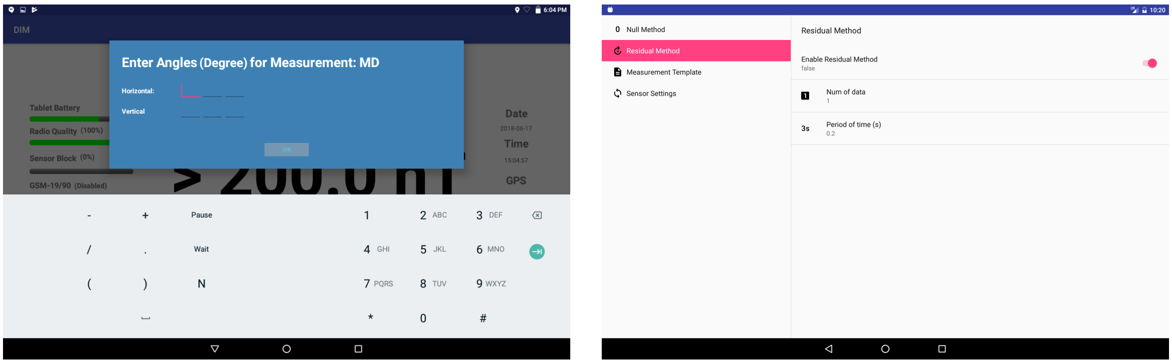

Figure 6: Screenshots of DIM application

4.2 The residual method

In the following section the procedure of absolute measurement according to the residual method will be given. It is supposed that the observer has some basic knowledge and skill in handling the theodolite, such as setting up the theodolite (ZM 4.1-4.2), leveling (ZM 4.3), adjusting the horizontal circle to reference azimuth (ZM 4.8), reading the horizontal and vertical circles (ZM 4.7), setting the horizontal or vertical circle to a given angle.

By using residual method the calibration and the polarity of the DI magnetometer are important. See the sections 2.2 and 2.3 of the FluxSet magnetometer user manual for more details! As the mechanical axes of the theodolite, the optical axis of the telescope and the magnetic axis of the FluxSet sensor always have some misalignment error, moreover, the theodolite may have further mechanical errors (collimation errors, non orthogonality error of the vertical and horizontal axis etc.), and as the offset of the electronics is not zero, the declination/inclination of the field can not be determined from a single reading of the horizontal/vertical circle. However, most of these errors are eliminated by the measuring process, using four position readings for each element.

1. **Leveling**
   Level the theodolite (ZM 4.3) already set up on the pier / on the tripod.

2. **Software initialization**
   Place the tablet on an easy-to-see free pier / spot at least 2 m away from the leveled theodolite. Turn on the tablet.

   2.1. **DIM application**
   Run the DIM application (figure 3a). As you can see on main page of DIM (figure 3b), plug the radio unit into the tablet's micro USB port. Press OK for the pop-up window (figure 3c). Turn on the FlxSet magnetometer on the telescope to establish connection between them (figure 3d). If the radio connection is successful then you will see sensor's output in the middle of the display (figure 3e).

   2.2. **Create a new file**
   For creating a new absolute magnetic measurement file, press the icon in the bottom left corner (figure 3e). Fill the cells with your desired input (figure 3f).

   2.3. **Select a measurement sequence**
   Click the icon in the bottom of the display (figure 3e). Make sure the residual method is selected (figure 4a). Set the number of measurement per position and the sampling time (figure 6b). Go to the measurement template (figure 4b). Click again the saved measurement template. Select your type (figure 4c). The next sensor position will be displayed according to the selected template on main page of *DIM*.

3. **Adjustment of the horizontal circle**
   Adjustment of the horizontal circle to the reference azimuth A_z (ZM 4.8.) can be done in different ways. This step is rather advised, than necessary. The goal of this step is to make the readings and calculations more comfortable, since in this case the horizontal readings taken during the observation of D will be close to the value:

$$D + n \cdot 90^\circ \quad \text{where} \quad n = -4, -3, \cdots + 4 \tag{3}$$

   Here the actual values of n depend on the declination and the difference between the azimuth and the horizontal reading of azimuth mark. This latter difference can be chosen to 0 (as in ZM 4.8), or $k \cdot 90^\circ$

$k = \pm 1$. Following the Hungarian standard procedure we will use a $-90°$ difference for the first position. Turn the telescope to have the sensor on the top (up position). With the telescope pointing to the azimuth mark, adjust the horizontal circle approximately to $A_z - 90°$. If $A_z - 90° < 0°$, add 360°.

4. **Observation of declination**

4.1. **Measurement of mark sighting in the 'sensor up position'**
Point the telescope to the azimuth mark (sensor up). Read the horizontal circle. Press the left button on the remote controller. Type the horizontal angle value in the MU (Mark up) pop-up window of the display (figure 6a).

4.2. **Measurement of mark sighting in the 'sensor down position'**
Invert the telescope to have the sensor on the bottom (sensor down position). Point the telescope to the azimuth mark. Read the horizontal circle. Press the left button on the remote controller. Type the horizontal angle value in the MD (Mark down) pop-up window of the display (figure 6a).

4.3. **Position East up**
Reverse back the telescope to have the sensor up again. Set the vertical index to exactly 90° (telescope horizontal). Rotate the alidade so that the telescope points roughly to the East. Fine adjust the alidade slowly searching for a nearly null position (some nT on the display of the tablet). A value less between -10 nT and 10 nT is recommended. Set the horizontal circle to a convenient value A_1. Read the horizontal circle. Press the left button on the remote controller. Type the horizontal angle value A_1 in the EU (East up) pop-up window of the display. The Universal Time (from the built in tablet GPS) $t_{r,EU}$, magnetometer output $S_{r,EU}$ will be saved by the application in the data table.

4.4. **Position West up**
Rotate the alidade with exactly 180° so that the telescope points roughly to the West $A_2 = A_1 + 180°$. Read the horizontal circle. Press the left button on the remote controller. Type the horizontal angle value A_2 in the WU (West up) pop-up window of the display. The Universal Time $t_{r,WU}$, magnetometer output $S_{r,WU}$ will be saved by the application in the data table.

4.5. **Position East down**
Turn the telescope to have the sensor down. Set the vertical index to exactly 270° (telescope horizontal). Now the telescope points roughly to the East A_2. Read the horizontal circle. Press the left button on the remote controller. Type the horizontal angle value A_2 in the ED (East down) pop-up window of the display. The Universal Time $t_{r,ED}$, magnetometer output $S_{r,ED}$ will be saved by the application in the data table.

4.6. **Position West down**
Rotate the alidade with exactly 180° to A_1. Read the horizontal circle. Press the left button on the remote controller. Type the horizontal angle value A_1 in the WD (West down) pop-up window of the display. The Universal Time $t_{r,WD}$, magnetometer output $S_{r,WD}$ will be saved by the application in the data table.

4.7. **Calculation of A and A_r**
The application will calculate A_r as

$$A_r = {}^1\!/\!_2 \cdot (A_1 + A_2) + m \cdot 90° \tag{4}$$

where $m = \pm 1$ for east/west declination. A_r is the angle of the approximative magnetic meridian (MM) in the theodolite reference frame (slightly differing from the azimuth of the MM).

5. **Observation of Inclination**

5.1. **Position North up**
Reverse back the telescope to have the sensor up again. Rotating the alidade set the horizontal circle to exactly $A_r + 270°$ (telescope in the meridional plane). Turn the telescope to point roughly to the North. Fine adjust the telescope slowly searching for a nearly null position. Read the vertical circle NU_r and the momentary total field $F_{r,NU}$. Press the left button on the remote controller. Type these values into the NU (North up) pop-up window of the display. The Universal Time $t_{r,NU}$, magnetometer output $R_{r,NU}$ will be saved by the application in the data table.

5.2. **Position South down**
Turn the telescope to point roughly to the South. Fine adjust the telescope slowly searching for a nearly null position. Read the vertical circle SD_r and the momentary total field $F_{r,SD}$. Press the

left button on the remote controller. Type these values into the SD (South down) pop-up window of the display. The Universal Time $t_{r,SD}$, magnetometer output $R_{r,SD}$ will be saved by the application in the data table.

5.3. **Position North down**
Rotate the alidade with exactly 180° ($Ar+90°$, telescope in the meridional plane). Turn the telescope to point the telescope roughly to the North. Fine adjust the telescope slowly searching for the a nearly null position. Read the vertical circle ND_r and the momentary total field $F_{r,ND}$. Press the left button on the remote controller. Type these values into the ND (North down) pop-up window of the display. The Universal Time $t_{r,ND}$, magnetometer output $R_{r,ND}$ will be saved by the application in the data table.

5.4. **Position South up**
Turn the telescope to point roughly to the South. Fine adjust the telescope slowly searching for a nearly null position. Read the vertical circle SU_r and the momentary total field $F_{r,SU}$. Press the left button on the remote controller. Type these values into the SU (South up) pop-up window of the display. The Universal Time $t_{r,SU}$, magnetometer output $R_{r,SU}$ will be saved by the application in the data table.

6. **Useful information**
If more set is taken the whole procedure must be repeated from the beginning. For setting the theodolite to the appropriate direction see figure 7.

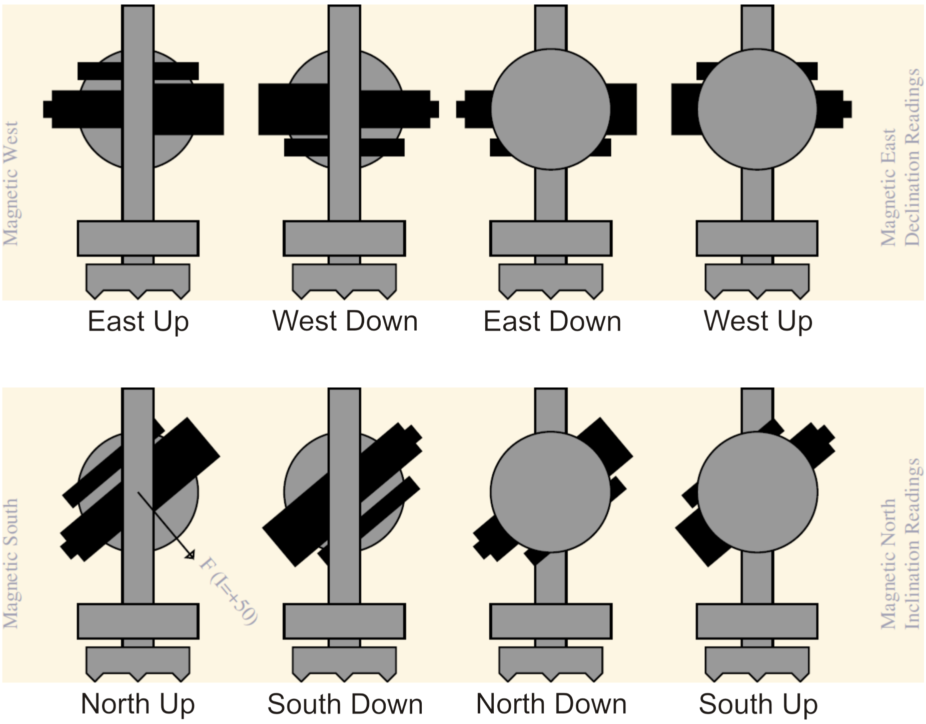

Figure 7: The theodolite directions of null/residual method [1994, Crosthwaite P]

5 Calculation of the components

Usually the goal of a DIM measurement is to obtain all the elements of the magnetic field, and therefore the DIM is combined with a **s**calar total field **m**agnetometer (SM). The simultaneous use of two instruments arises a new problem as all the measurements must be referred to the same point (in an observatory to the absolute pier). That means that the total field difference

$$dF = F_{DIM} - F_{SM} \tag{5}$$

of the two places has to be measured. It is generally not more than a few or a few tens of nT for sites close to each other as there is no sense in making measurements in a place where the field gradient is high. The mean total field is calculated as the mean of the four readings corrected with site difference:

$$F_{abs} = {}^1\!/_4 \cdot (F_{NU} + F_{SD} + F_{ND} + F_{SU}) + dF \tag{6}$$

Important! When using the residual method now you need to calculate A as follows:

$$\begin{aligned}
EU =& A_1 + {}^{180^\circ}\!/_{\pi} \cdot {}^{S_{r,EU}}\!/_{H} \\
WU =& A_2 + {}^{180^\circ}\!/_{\pi} \cdot {}^{S_{r,WU}}\!/_{H} \\
WD =& A_2 + {}^{180^\circ}\!/_{\pi} \cdot {}^{S_{r,WD}}\!/_{H} \\
ED =& A_1 + {}^{180^\circ}\!/_{\pi} \cdot {}^{S_{r,ED}}\!/_{H} \\
A =& {}^{1}\!/_{4} \cdot (EU + WU + ED + WD) + m \cdot 90^\circ
\end{aligned} \tag{7}$$

where $m = \pm 1$ for east/west declination. A is the angle of the magnetic meridian (MM) in the *theodolite reference frame (slightly differing from the azimuth of the MM). The mean declination is given by:

$$D_{abs} = A + A_z - M \tag{8}$$

where A_z is the azimuth of the reference mark, A is the mean of the four horizontal circle readings, which has been already calculated at the end of the declination observation process, M is the mean of the measurements of reference mark sighting (MU, MD) corrected with 180°:

$$M = {}^{1}\!/_{2} \cdot (MU + MD) - 180^\circ \tag{9}$$

The mean inclination is the mean of the four vertical circle readings taken during inclination observation process, corrected:

$$I_{abs} = {}^{1}\!/_{4} \cdot (NU + SD - ND - SU) + 90^\circ \tag{10}$$

Important! When using the residual method the above values can be calculated as:

$$\begin{aligned}
NU =& NU_r - {}^{180^\circ}\!/_{\pi} \cdot {}^{R_{r,NU}}\!/_{F} \\
SD =& SD_r + {}^{180^\circ}\!/_{\pi} \cdot {}^{R_{r,SD}}\!/_{F} \\
ND =& ND_r + {}^{180^\circ}\!/_{\pi} \cdot {}^{R_{r,ND}}\!/_{F} \\
SU =& SU_r - {}^{180^\circ}\!/_{\pi} \cdot {}^{R_{r,SU}}\!/_{F}
\end{aligned} \tag{11}$$

Horizontal H, vertical Z, North X and East Y intensities can be expressed as:

$$\begin{aligned}
H_{abs} =& F_{abs} \cdot cos(I_{abs}) \\
Z_{abs} =& F_{abs} \cdot sin(I_{abs}) \\
X_{abs} =& H_{abs} \cdot cos(D_{abs}) \\
Y_{abs} =& H_{abs} \cdot sin(D_{abs})
\end{aligned} \tag{12}$$

6 Determination of the baseline of a variometer

In observatories absolute measurements are regularly taken to determine the baseline values for continuously running variometers. Variometers are installed to measure the three components of the magnetic field in a usually orthogonal reference system, mainly in XYZ or in HDZ system. However, variometers generally measure not the total components, but only the momentary deviation of the component from a fairly stable but unknown level. This level is called the baseline for the corresponding component. Even if a variometer measures approximately the whole components, the reference level or the offset of a component is changing in time because of mechanical, temperature, etc. changes. Therefore to ensure the expected accuracy the baseline determination as a regular, partial calibration process of variometers is unavoidable.

6.1 Baseline calculation in the XYZ system

The baseline calculation in a coordinate system means simply the calculation of the difference between the total component value given by the absolute measurement, and the corresponding mean variation for each component, i.e:

$$\begin{aligned}
X_{base} =& X_{abs} - dX \\
Y_{base} =& Y_{abs} - dY \\
Z_{base} =& Z_{abs} - dZ
\end{aligned} \tag{13}$$

where X_{abs}, Y_{abs}, Z_{abs} are produced by the absolute measurement, while dX, dY, dZ values are means of the component values taken at times corresponding to specific absolute measurement steps as follows:

$$\begin{aligned} dX &= {}^1\!/\!_4 \cdot [dX(t_{NU}) + dX(t_{SD}) + dX(t_{ND}) + dX(t_{SU})] \\ dY &= {}^1\!/\!_4 \cdot [dY(t_{EU}) + dY(t_{WU}) + dY(t_{ED}) + dY(t_{WD})] \\ dZ &= {}^1\!/\!_4 \cdot [dZ(t_{NU}) + dZ(t_{SD}) + dZ(t_{ND}) + dZ(t_{SU})] \end{aligned} \tag{14}$$

6.2 Baseline calculation in the HDZ system

In the HDZ system the procedure is similar, but first the result of the absolute measurement should be converted in HDZ system as follows:

$$\begin{aligned} H_{abs} &= +X_{abs} \cdot cos(D_0) + Y_{abs} \cdot sin(D_0) \\ D_{abs} &= -X_{abs} \cdot sin(D_0) + Y_{abs} \cdot cos(D_0) \end{aligned} \tag{15}$$

where D_0 is the angle between the magnetometer H-axis and the true north, which depends on the installation procedure of the variometer.

$$\begin{aligned} H_{base} &= H_{abs} - dH \\ D_{base} &= D_{abs} - dD \\ Z_{base} &= Z_{abs} - dZ \end{aligned} \tag{16}$$

where

$$\begin{aligned} dH &= {}^1\!/\!_4 \cdot [dH(t_{NU}) + dH(t_{SD}) + dH(t_{ND}) + dH(t_{SU})] \\ dD &= {}^1\!/\!_4 \cdot [dD(t_{EU}) + dD(t_{WU}) + dD(t_{ED}) + dD(t_{WD})] \\ dZ &= {}^1\!/\!_4 \cdot [dZ(t_{NU}) + dZ(t_{SD}) + dZ(t_{ND}) + dZ(t_{SU})] \end{aligned} \tag{17}$$

Baseline calculation yields also a possibility to check the consistency of DIM measurements, and to compare two or more DIMs.

7 Adjustment of sensor orientation and electronics offset

7.1 The estimation of misalignment errors and offset

The fluxgate sensor mounted on the telescope has two misalignment errors, one in the horizontal (δ) and another one in the vertical plane (ϵ), supposing a horizontal telescope. The horizontal misalignment can be estimated from the four horizontal reading taken during declination observation:

$$\delta = {}^1\!/\!_4 \cdot (EU + WU - ED - WD) \tag{18}$$

The vertical misalignment can be estimated from the four vertical reading taken during inclination observation:

$$\epsilon = -{}^1\!/\!_4 \cdot (NU + SD + ND + SU) + 180^\circ \tag{19}$$

The offset of the electronics estimated from both sequences:

$$O_I = -F \cdot {}^{\pi}\!/\!_{180^\circ} \cdot [{}^1\!/\!_4 \cdot (NU - SD - ND + SU) + 90^\circ] \tag{20}$$

where F can be an approximative value.

7.2 Readjustment of sensor

Whenever the misalignment error succeed a certain limit depending partially on the user, the sensor should be readjusted. It is important to note that these errors are eliminated by the measuring process, however it is not wise to make measurements when these errors surpass 10 minutes of arc.

Step 1

Follow the steps of the absolute measurement. For this process we will need the theodolite readings only, but not the total field values, time etc. Calculate ϵ.

Step 2

Still in the South up position correct the vertical angle with ϵ, i.e. set $SU + \epsilon$ on the vertical index. Now the magnetometer will display a non-zero value.

Step 3

Using the non-magnetic tool fine adjust the upper screw until the magnetometer reading gets close to 0 nT (a few nT may be satisfactory).

Step 4

Check the vertical reading. Repeat Step 1, 2, 3 and 4 if necessary.

Step 5

Follow the steps of the absolute measurement until you get the actual value of A. Calculate δ.

Step 6

In the East up position correct the horizontal angle with δ, i.e. set $EU - \delta$ on the horizontal index. Now the magnetometer will display a non-zero value.

Step 7

Using the non-magnetic tool fine adjust the lateral screw until the magnetometer reading gets close to 0 nT (a few nT may be satisfactory).

Step 8

Check the horizontal reading and the horizontality. Repeat Step 5, 6, 7 and 8 if necessary.

Step 9

Finish the absolute measurement to determine the actual value of ϵ and δ.

The whole process is an iterative one. These 9 steps can be regarded as the first iteration. It is possible, that two or more iterations are needed for a satisfactory result. The process and all equations suppose quiet magnetic field. The readjustment of the sensor is not effective during very disturbed geomagnetic conditions.

7.3 Setting the offset

The offset can be reduced inside the android application.

Step 1

Click on the main page the .

Step 2

Then click sensor settings. Click sensor offset.

Step 3

Type into the cell the calculated O_I offset value. Check the offset. Repeat Step 1, 2 and 3 if necessary.

8 Technical parameters

The general technical parameters of the theodolite. See the ZM for more details!

Measuring accuracy	Theo 20 Theo 15	Theo 10
Mean squared error of a direction measured face left/right	± 1.0mgon$=\pm 3.2''$ ± 0.8mgon$=\pm 2.6''$	± 0.3mgon$=\pm 1.0''$
Of treble repeated angle measured face left/right	± 0.3mgon$=\pm 1.0''$	

Telescope	Theo 20 Theo 15	Theo 10
Image position	erect and true-to-side	
Magnification	30x	
Free objective diameter	40mm	
Length	180mm	
Angle of field	1.3°	
Field of vision at 1 km	23m	
Shortest sighting distance	1.5m	
Longest sighting distance (cm- divided staff) for estimation to ±0.5 mm for reading to ±0.5 cm	 120m 500m	
Multiplication constant	100	
Addition constant	0	

Dimension (cm)	Theo 20 Theo 15	Theo 10
Height of instrument	33.4	
Height of tilting axis	22.4	
Diameter of central pivot for controlled centering (TGL 34-133, DIN 18719)	 3.4	
Metal container	42x23x19	
Tripod 3v (extensible legs)	100	160
Tripod 3s (non-extensible)	150	

Weight (kg)	Theo 20 Theo 15	Theo 10
Instrument	4.5 4.8	4.8
Metal container		4.4
Carrying device	0.3	
Tripod 3v	6.5	
Tripod 3s	7.0	

Magnetic hygiene
The magnetic contamination of the theodolite everywhere is less than 1 nT at 1 cm distance from the surface of the instrument.

Sensor alignment
Initial horizontal misalignment $< 45''$
Initial vertical misalignment $< 20''$

These values may change with time, temperature, especially during transportations.
It should be emphasized that the accuracy of the measurements does not depend on the magnitude of the sensor misalignment errors and of the offset within reasonable limits, so complete canceling these errors is not necessary.

9 General Description of the FluxSet DIM

It uses a FLUXSET© sensor with a low noise electronics giving a digital output stable to 0.1 nT and an initial offset lower than 1 nT (adjustable). Magnetometer and sensor is mounted on the telescope while tablet is a separate unit. Magnetometer data are transmitted to the tablet by a radio link. A barcode display giving information if the sensors output is outside of measurement range.

Optional data recording
Measured magnetometer data with precise time stamp can be recorded by a data logger optionally supplied with the magnetometer. After the measurement session all data can be downloaded from the tablet to a processing PC with the packed USB cable.

Power supply

The DI magnetometer has built-in battery which may be charged with 5V DC charger. All batteries ensure more then 6 hours operation. The tablet can be recharge via USB charger.