Instruction Guide

PHOTON SYSTEMS INSTRUMENTS

LaiPen LP 110

Please read the Guide before operating this product

Manual Version: 2023/11

www.psi.cz

TABLE OF CONTENT

1 INFORMATION BEFORE USING THE DEVICE

Carefully unpack the carton. You should have received the following items:

- LaiPen LP 110
- Carrying case
- Textile strap for comfortable wearing
- Installation USB flash drive with FluorPen software, USB driver and this guide
- Connection cable (4 Pin Male to USB 2.0 A Male)
- Other accessories or features based on specific order

If any item from the list above is missing, please, contact PSI. Also check the package for any visible external damage. If you find any damage, notify the carrier and PSI immediately. The carton and all packing materials should be retained for inspection by the carrier or insurer.

For customer support, please write to: support@psi.cz

Before starting operation of the instrument read this manual carefully and follow the instructions. If you are not sure about anything in the manual, contact the manufacturer for prominence. By taking this device, the customer agrees to follow the instructions in this guide. Always follow the specific instructions for use and maintenance of equipment and its accessories. It is forbidden to interfere to the hardware and software part of the device and its accessories.
Copying or other interference in software is considered copyright infringement and is sanctioned in accordance with the relevant legislation. These activities can also lead to loss of warranty on the device and its accessories. Those activities may also cause damage to health and property.

Read this manual carefully before operating the device. If you are not sure about something in the manual, contact the manufacturer for clarification.

	By accepting the device, the customer agrees to follow the instructions in this guide.

Always follow corresponding manuals while working with the device or doing the maintenance. It is forbidden to interfere with the hardware or software of the device in any way without previous agreement with the manufacturer.

The following table presents basic highlight symbols used in this manual:

Symbol	Description
	Important information, read carefully.
	Complementary and additional information.

2 Device Description and Accessories

Instrument for fast and easily repeatable measurements of Leaf Area Index (LAI) from solar radiation. The LaiPen was designed by scientists and engineers to provide instant readouts that can be exported to computer for further processing. Unlike in other similar instruments measuring LAI, the LaiPen LP 100 is accurate in most daylight conditions and does not require cloud cover or specific sun angles for its proper performance. ALAI irradiance is an irradiance of the blue part of visible spectrum and can be measured with a LAI sensor, which is placed on a side of the LaiPen instrument. The LAI sensor is covered with a black restriction cup (Fig. 1). PAR can be measured with a PAR sensor, which is placed in the middle of the front side of the instrument (Fig. 1).

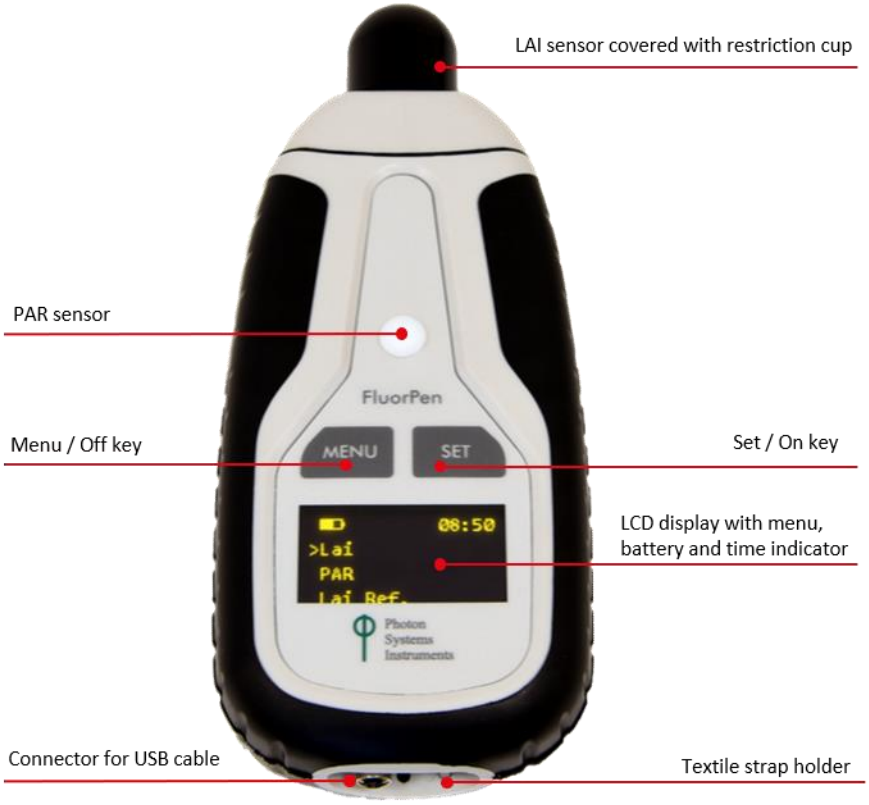


Fig. 1 LaiPen LP 110 Physical Features

LaiPen device is supplied with the following items:

- Connection cable
- Padded carrying case to protect the instrument during transportation (Fig. 2)
- Control software and manual on a USB stick
- Textile strap

Fig. 2 Padded carrying case to protect the instrument during transportation

2.1 ACCESSORIES

2.1.1 NOTEBOOK COMPUTER

Portable notebook computer (laptop). The type and specification vary according to current availability on the market. For detailed information contact PSI at support@psi.cz

2.1.2 TELESCOPIC ROD

LaiPen instrument attached to a telescopic rod can facilitate measurements of distinct vegetation canopy layers at different heights. It can also be used to measure reference values above canopy of mid –sized plants or shrubs. Acoustic indicator on the LaiPen device would indicate completion of each remote measurement through sudden changes in beeping tone and frequency.

Fig. 3 Telescopic rod

2.1.3 TRIPOD

Reference measurement in dual sensor mode can be achieved only with the LaiPen instrument mounted to a stable construction in an open area. Portable light telescopic tripod can provide such a fixed reference point.

Fig. 4 Tripod

2.1.4 SUBSTITUTE CONNECTION CABLE

Substitute connection cable (4 Pin Male to USB 2.0 A Male) allows communication between the LaiPen device and the PC. The LaiPen device is delivered with one connection cable included in price of device.

Fig. 5 Substitute connection cable

3 TECHNICAL SPECIFICATIONS

LAI Pen 110	
Measured and calculated parameters	Photosynthetically active radiation (PAR, 400 – 700 nm) ALAI radiation (blue band of the spectrum, 400–500 nm) PAR index calculated as PAR transmittance through canopy ALAI index calculated as ALAI transmittance through canopy
Measurement at multiple zenith angles:	0°, 16°, 32°, 48°, 64°
View Restricting Cap:	Horizontal field of view: 112° Vertical field of view: 16°
Memory Capacity	16 MB
Internal Data Logging	Up to 100,000 data points
Actinic Illumination	Horizontal field of view: 112°
Detector Wavelength Range:	PAR measurement: 400 – 700 nm band pass filter ALAI measurement: 400 - 500 nm band pass filter
Detector	PIN photodiode with bandpass filters
Data transfer	Connection cable Bluetooth (transfer up to 3 Mbps for distance up to 20 m)
PC software	FluorPen
Battery	Li-Ion rechargeable battery Capacity 2000 mAh Max. charging current 0.5 A Charging via USB port - PC, power bank, USB charger, etc. 48 hours typical with full operation, low battery indicator
Keypad	Sealed, 2-key tactile response Turns off after 5 minutes of no use
Built in GPS module	Ultra-high sensitivity down to -165 dBm High accuracy of < 1.5 m in 50 % of trials
Size	120 x 57 x 30 mm
Weight	180 g
Operating conditions	Temperature: 0 to +55 °C Relative humidity: 0 to 95 % (non-condensing)
Storage conditions	Temperature: -10 to +60 °C Relative humidity: 0 to 95 % (non-condensing)
Warranty	1-year parts and labor

Bluetooth module compliance data		
Category	Country	Standard
Radio	USA	FCC Part 15 Subpart B: 2008 Class B FCC CRF Title 47 Part 15 Subpart C
	FCC ID:	T9J-RN42
	Europe	ETSI EN 301 489-1 V1.8.1 ETSI EN 301 489-17 V2.1.1 ETSI EN 300 328 V1.7.1
	Canada	IC RSS-210 low power comm. device
	Certification number:	6514A-RN42
EMC	USA	FCC CFR47 Part 15 subclass B
	Europe	EN 55022 Class B radiated EN61000-4-2 ESD immunity EN61000-4-3 radiated field EN61000-4-6 RF immunity EN61000-4-8 power magnetic immunity

4 Principle of Measurement

4.1 Measured Parameters

Photosynthetically active radiation (PAR) is quantified as µmol photons $m^{-2}s^{-1}$, which is a measure of the photosynthetic photon flux density (PPFD). The percent proportion of photosynthetic photon flux density (% PPFD) below a canopy can be interpreted as the canopy PAR transmittance. PAR transmittance linearly correlates with canopy gap fraction, which is a parameter used to quantify probability of solar radiation penetration through the canopy using photographs. LaiPen LP 100 can measure PAR irradiance with the use of PAR sensor (see Fig.1) in a single wide angular detection range.

Leaf Area Index (LAI) is defined as one-sided green leaf area per unit ground surface area (LAI = leaf area/ ground area, m^2 / m^2) in broadleaf canopies.

Although absorption of PAR by the vegetation canopy is sufficient for LAI calculation, LaiPen LP 100 is also offering to measure irradiance of the blue part of solar radiation (400-500 nm) with LAI sensor (Fig.1). This irradiance, here designated as ALAI irradiance, is the most efficiently absorbed part of the spectrum by green leaves, and therefore is more convenient for LAI calculation than PAR.

The LAI sensor is a single optical sensor used in conjunction with a view restriction cup (Fig.1) restricting the LAI sensor view to 16^0 (Z axis) and 112^0 angle (X axis). ALAI transmittance is measured by holding the instrument either vertically in zenith direction (i.e. zenith angle 0°), or by subsequent inclination into five zenith angles: 0°, 16°, 32°, 48° and 64°**.**

LAI is then calculated from ALAI transmittance or PAR values after downloading the readouts from the LaiPen device to a computer equipped with a spreadsheet software (e.g. MS Excel). Light transmittance below vegetation canopy (either PAR or ALAI) is then calculated as irradiance from below the canopy divided by irradiance values from above or next to the canopy:

$T = I / I_0$ *(Equation 1),*
where I is irradiance intensity below the canopy, I_0 is irradiance falling on vegetation (reference irradiance).

LAI is defined as the leaf area above the ground surface area: LAI = leaf area / ground area (units: m^2/m^2 or ha^2/ha^2) and then can be considered dimensionless. Methods of LAI determination, which are based on measuring irradiance intensity rely on the fact that intensity of irradiance decreases exponentially when it passes through vegetation canopy according to Lambert-Beer extinction law modified by Monsi - Saeki (Hirose, 2005):
$I = I_0 e^{(-k LAI)}$ *(Equation 2),* hence
$LAI = - \ln (I / I_0) / k$ *(Equation 3),* where

I is the irradiance intensity under the canopy, I_0 is the intensity of irradiance above the vegetation, e is Euler's number and k is extinction coefficient. Extinction coefficient is estimated from shape, orientation and position of each element of vegetation canopy with a known inclination of canopy element and view direction (Breda, 2003).

As the values of extinction coefficient are usually close to 0.5 (e.g. Pierce and Running, 1988), the equation 3 can be simplified as presented by Lang et al. (1991):
LAI = 2 |∅ln t| for inhomogeneous canopies *(Equation 4)* or
LAI = 2 |ln∅ T| for homogeneous canopies *(Equation 5),*
where t is transmitance at each canopy measurement point and T is average transmitance of all t values per transect or stand.

After the initial calculation, LAI must be further corrected by proportion of woody elements surface area (WAI). Measurement below canopy of coniferous trees requires further corrections of the LAI due to clumping of needles within shoots (Stenberg et al , 1999).

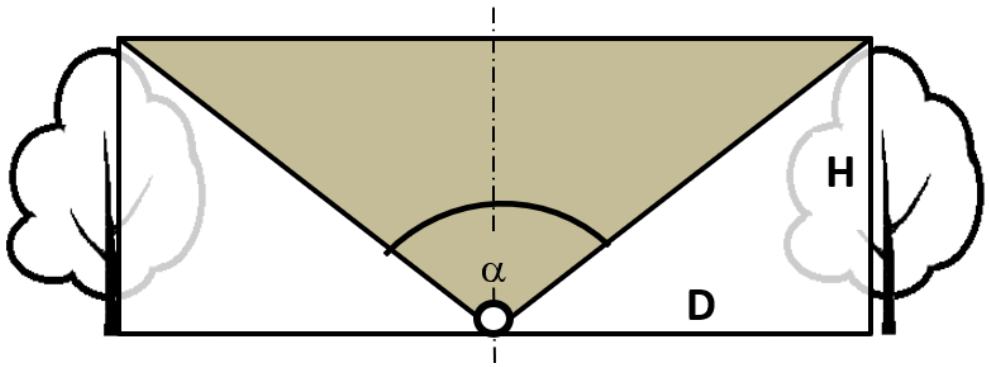
	The initial LAI value uncorrected to the final value is often referred to effective LAI (LAIe). Correcting the LAIe value to the final LAI value may not be always necessary (e.g. comparing groups with equal correction factors).

4.2 Measuring Reference

4.2.1 Distance Nearest Shading Obstacle

Light transmittance through vegetation canopy is calculated from two irradiance values

$T = {}^{I}/_{I0}$ *(Equation 1*).
Irradiance measured below the canopy is divided by reference irradiance value measured either above the vegetation canopy or in an open space without obstacles, which can cause shading. The reference measuring point in an open space depends on the view angle of the light meter sensor (PAR or LAI) and the height of the nearest obstacle (see Fig. 6). The minimum recommended distance (D) for all LaiPen reference measurements is approximately 1.5 multiple of the nearest obstacle height.



H (m)	D (m)
5	7,4
10	14,8
15	22,2

Fig. 6 Distance from the nearest obstacle.

Distance (D) from the operator (black circle) to the nearest obstacle (tree drawing) is dependent on the height of the nearest obstacle (H) and the LaiPen maximum view angle α shown in grey (α=112˚). The enclosed table states minimum recommended distance values (D) for three obstacle heights (H).

4.2.2 Measurement Relative to the Sun

Measurement of ALAI irradiance with LAI sensor is dependent on field of view of the restricting cap. Since the angle of view is wide open (112° in one axis), it is essential to prevent direct sunlight entering the view restriction cup. The overexposure of a LAI sensor could lead to misinterpretation of actual light condition. Before each measurement, it is necessary to position the instrument as described in Fig. 7. to obey the principle, that during measurement, the LAI sensor is never exposed to direct sunlight. Correct positioning of the LaiPen relative to the sun does applies not only for obtaining correct reference values, but also for measurements below in-homogenous canopies with incidental direct sunlight.

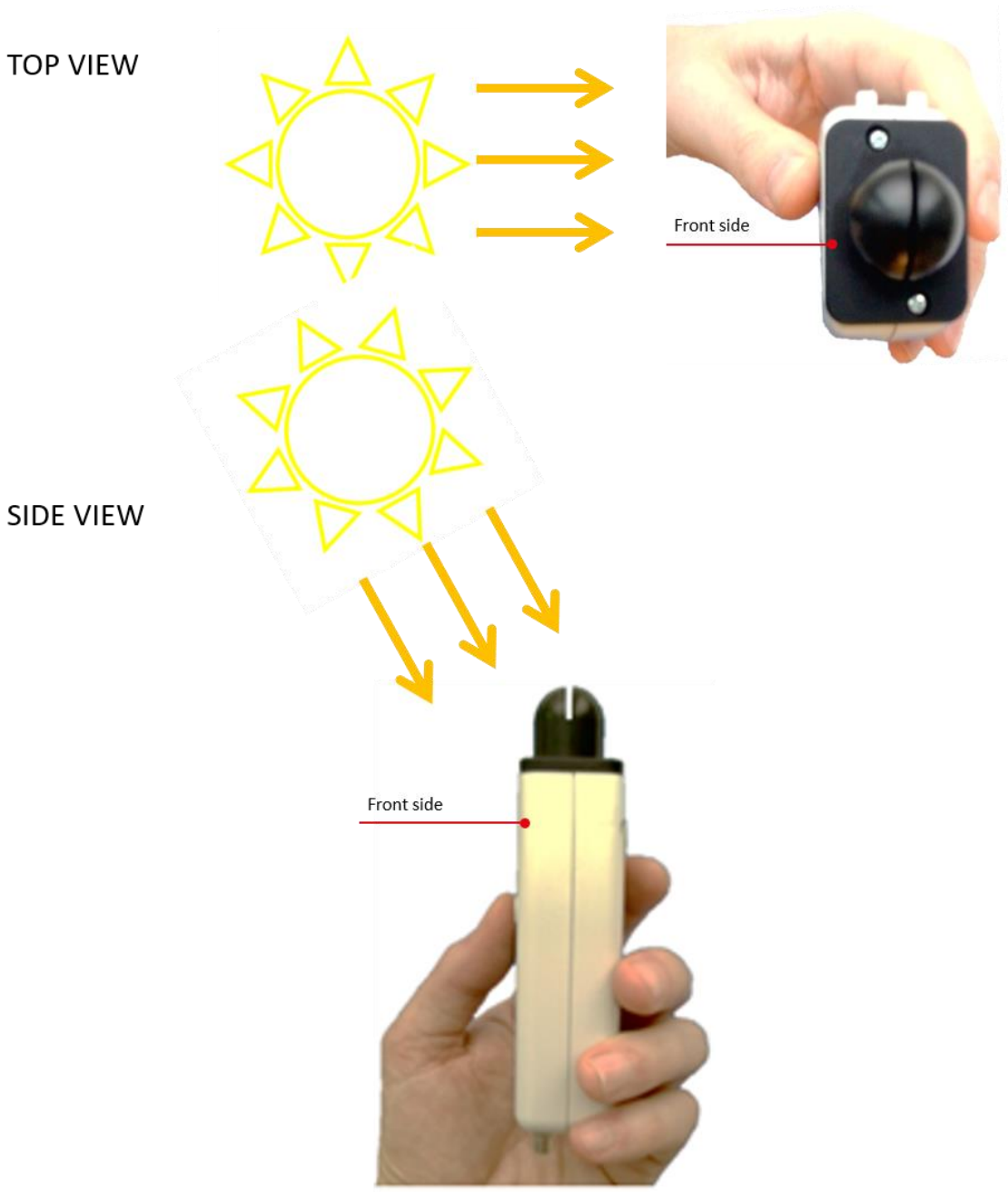


Fig. 7 Instrument positioning in relation to the sun position.

In order to prevent direct sunlight exposure of the LAI sensor, it is necessary to turn with the instrument around to correct position of the restriction cup relative to the sun. Hold the instrument vertically and turn around with the device so the slot of the restriction cup is oriented perpendicularly to sunlight direction and the front (display) side of the device would face the sun.

4.2.3 Reference for Single Sensor Mode of Measurement

In single sensor mode of measurement, reference readings are measured with the same instrument as the readings below canopy. Reference readings are acquired before, after or even during the process of systematical measurement below the canopy. Transmittance values are then calculated as dividing a canopy reading by a parallel reference value, which is estimated for the moment of canopy reading. The parallel reference values are estimated as weighted average of two neighboring reference readings on the timeline (Fig. 8).

	Single sensor mode of measurement is advised to be used preferably at constant light condition (clear or overcast sky condition) as rapid changes of weather might cause inaccurate prediction of reference irradiance values, which are necessary for correct LAI calculation.

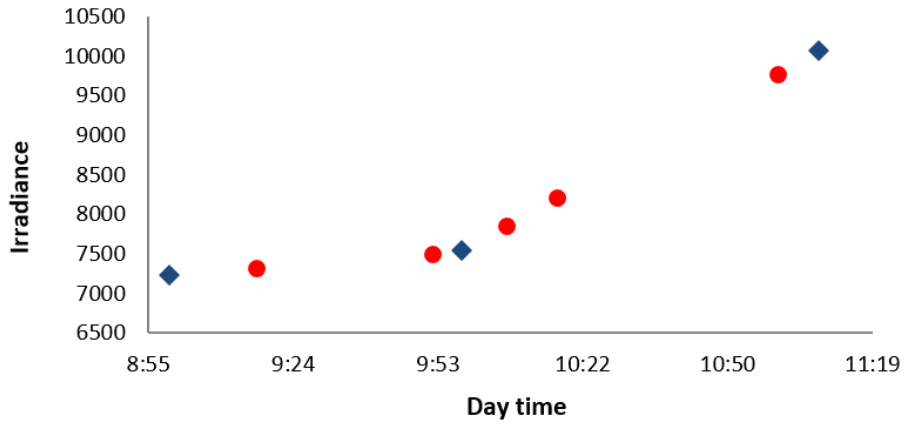


Fig. 8 Calculation of reference values by FluorPen software in single sensor mode.

Reference values are computed as weighted average of two neighbouring reference readings on the timeline. Reference readings in this example were taken before, after and during the measurement with the same instrument. ◆ Measured reference values, ● reference values estimated for light transmittance calculation of canopy measurement.

4.2.4 Reference for Dual Sensor Mode of Measurement

In dual sensor mode of measurement two sensors are employed in parallel. One instrument is fixed in an open space for automatic logging of reference readings in pre-defined time intervals, while the other instrument is used for hand-operated measurement under the vegetation canopy (canopy readings). Transmittance values are then calculated as dividing a canopy reading by a parallel reference value, which is estimated for the moment of canopy reading. The parallel reference values are estimated as weighted average of two neighbouring reference readings on the timeline (Fig. 9). The dual sensor method collects considerable amount of reference data, thus increases accuracy in estimation of reference values.

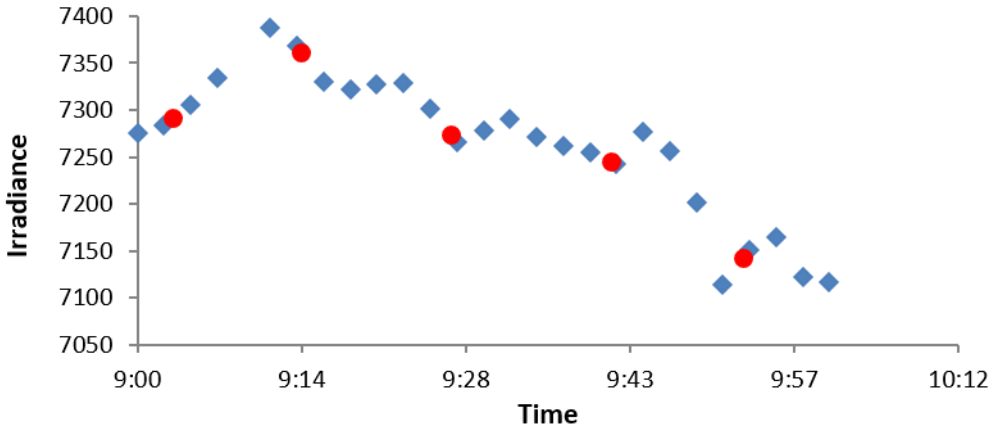


Fig. 9 Calculation of reference values by FluorPen software in dual sensor mode of measurement.

Reference values are computed as weighted average of two neighboring reference readings, which were acquired by automatic logging in 2 min intervals. ◆ Automatic logging of reference readings, ● reference values estimated for each moment of canopy measurement. The estimates are then used for calculation of light transmittance.

5 GETTING STARTED

5.1 GENERAL GUIDE TO MEASUREMENT

This chapter explains how to start to operate the LaiPen LP110/USB in single sensor or in dual sensor mode of measurement. Single sensor mode of measurement of ALAI irradiance can be used for measuring multiple angles, which is described in chapter 5.5. For more detailed information on particular steps of LaiPen operation refer to chapter 5.

PAR can be measured with a PAR sensor, which is placed in the middle of the front side of the instrument (see Fig. 1). During measurement the instrument must be placed horizontally with the PAR sensor facing upward (see Fig. 10, left panel).

ALAI irradiance is an irradiance of the blue part of visible spectrum and can be measured with a LAI sensor, which is placed on a side of the LaiPen instrument. The LAI sensor is covered with a black restriction cup (see Fig. 1). Two modes of ALAI measurement in respect to zenith angle are available. The single angle mode allows to obtain ALAI readings with LAI sensor pointing to zenith only (Fig. 6, right panel). The multiple angle mode guides through measurement of five zenith angles: 0°, 16°, 32°, 48° and 64°. Operation instructions for using the instrument in single angle or multiple angle mode are described in detail in chapters 5.3 - 5.5.

Fig. 10 Measurement of PAR and ALAI irradiance.

PAR irradiance is measured with horizontally oriented device (left), while ALAI irradiance is measured with ALAI sensor pointing upward (right).

Operation of the LaiPen can be enhanced with global positioning system. GPS receiver is switched on to receive satellite signal and then the receiver is carried with the device during canopy measurement. The software can pair the irradiance readings with GPS coordinates for each measuring point. For detailed instructions refer to chapter 11.

The following measurement procedures describe common methods of LAI determination from ALAI irradiance. For more detailed information about the LaiPen software and how to handle acquired data refer to the chapters 6 to 9.

5.2 DARK CALIBRATION PRIOR TO MEASUREMENT

The LaiPen device should be calibrated for internal detector settings before each round of measurement or after switching ON the device. Immediately after completion of each calibration procedure zero value appears on the display indicating successful calibration. Set the internal date and time ***Main Menu > Settings > Time*** before first measurement or after battery replacement.

Prior to each measurement calibrate the LAI optical sensor to the dark. Before starting the dark calibration procedure prepare a piece of dark cloth.

1. Switch on the instrument by pressing and holding ***SET*** button for 1 second.
2. Select ***Main Menu > Settings > LAI Cal*** and check whether the LAI calibration constant is set to 1 (c = 1.0), if not press ***SET*** repeatedly to adjust the constant to 1.0. This feature allows to adjust detector settings of one instrument to another, which is used for dual sensor mode of measurement. In case of measuring in single sensor mode keep the constant set to 1.0 for all measurements.
3. Select ***Main Menu > Settings > LAI Zero***. Cover the front LAI sensor competely with dark thick cloth or simply by a thumb and hold it tightly during the process of calibration to ensure complete darkness. It is important that no surrounding light can interfere with the measurement during the calibration step. Then press ***SET*** and stable zero value appears on the display.
4. To return to the main menu press ***MENU*** repeatedly until ***Return*** is selected and then press ***SET***.

5.3 SINGLE SENSOR MODE OF MEASUREMENT

This chapter describes a particular measurement procedure with single LaiPen instrument operating in one zenith angle. Example in chapter 5.6 describes how to perform the zenith angle measurements systematically to determine LAI in vegetation cover.

	It is advised to use single sensor mode of measurement preferably at constant light conditions as rapid changes of weather can cause inacurate LAI calculation.

1. Switch on the instrument by holding ***SET*** button for 1 second.
2. Calibrate the LaiPen to the dark condition (see chapter **Error! Reference source not found.**)
3. Set the LaiPen or make sure it is set to single angle mode of measurement ***Main Menu > Settings > Angles > Single***
4. If you want to use GPS device, turn it on and carry the device during all canopy measurements with the LaiPen device (see chapter 6).
5. Take reference measurement in an open space. In sunny weather condition avoid entering direct sunlight into the view restricting cup (see chapter 4.2.2).
   5.1. Set ***Main Menu > Measure > ARef*** after pressing ***SET*** online measurement of reference value is activated. Irradiance value is continuously monitored, actual value appears on the display. Please note that these values are not stored to internal memory of the device.
   5.2. To acquire reference value, which must be obtained in the zenith angle, follow the next step. Press ***SET*** again to start the navigation for obtaining the zenith angle position of the ALAI sensor. Reference value is automatically acquired and stored. Internal inclinometer and acoustic beeping indicator are activated. Readings of angle degrees for current position of Lai sensor appear on the display for both X and Z axis. Angle of the zenith position, which is necessary for LAI measurement is defined by X and Z axis equal to 0.
   5.3. Then place the LaiPen vertically with the ALAI sensor pointing up to the zenith. The acoustic indicator would switch from low tone to high tone beeping when the current position of the instrument is reaching an angle, which is close to the target (zenith).
   5.4. Watch the display, tilt the instrument in left-right direction and in forward-backward direction to achieve the lowest angle for both readings (X and Z axis) and carefully try to reach the zenith angle. This step can be sometimes tedious since the correct position must be achieved in range of milometers.
   5.5. Reference measurements proceed automatically, when the correct position is reached. This is indicated by increased frequency of beeping after which beeping tone is interrupted. At the same time the measured value is displayed temporarily in format "REF X = value", where X is the measurement number and the value is stored to internal memory. Then the instrument would switch back to continuous reading mode.
6. In the next step transmittance measurement under the canopy is described. Define position under the vegetation canopy and start the ALAI value measurements.
   6.1. Go to ***Main Menu > Measure > ALAI***. After pressing ***SET*** online measurement of ALAI irradiance is activated. Irradiance value is continuously monitored, actual value appears on the display. These values are not stored to internal memory of the device.
   6.2. To acquire ALAI value, which must be obtained in the zenith angle, follow the next step. Press ***SET*** again to start the navigation for obtaining the zenith angle position of the ALAI sensor. ALAI values are automatically acquired and displayed. First, internal inclinometer and acoustic beeping indicator are activated. Detailed readings of angle degrees to zenith direction appear on the display for both X and Z axis.
   6.3. Then position the LaiPen vertically with the Lai sensor pointing up to the zenith. The acoustic indicator would switch from low tone to high tone beeping when the position of the instrument is reaching an angle, which is close to the target (zenith).
   6.4. Watch the display, tilt the instrument in left-right direction and in forward-backward direction to achieve the lowest angle for both readings (X and Z axis) and carefully reach the zenith angle. This step can be sometimes tedious since the correct position must be achieved in range of millimeters.
   6.5. Measurement proceeds automatically, when the correct position is reached. This is indicated by increased frequency of beeping after which beeping tone is interrupted. At the same time the measured value is displayed temporarily in format "ALAI X = value", where X is the measurement number and the value is stored to internal memory. Then the instrument would switch back to continuous reading mode.
7. Proceed to further ALAI measurements under vegetation canopy. You can also measure reference values anytime in between the ALAI measurements (e.g. after completion of each transect); it will increase precision of the reference value prediction.

8. Soon after completing measurement under vegetation canopy obtain the last reference value in an open space.
9. To return to the main menu press ***MENU*** repeatedly until ***Return*** is selected and then press ***SET***.
10. After each measurement the data is stored to the device internal memory and the instrument can be switched off by holding ***MENU*** button for 1 second safely without erasing data.
11. Connect the instrument to computer and download data (see chapter 9.3). For example, of field measurement and LAI calculation refer to chapter 4.6.

5.4 Dual Sensor mode of Measurement

In dual sensor mode of measurement one instrument is fixed on a tripod and used for automatic logging of reference signal in pre-defined time interval (instrument_1). The other instrument is used for hand-operated measurements below vegetation canopy (instrument_2). Example in chapter 4.6 describes how to perform zenith angle measurements for subsequent LAI calculation in vegetation cover.

1. Switch on both instruments by holding ***SET*** button for 1 second and set the actual date and time if necessary (***Main Menu > Settings > Time***). Instrument_1 will be used for reference measurements, instrument_2 for canopy measurements.
2. Calibrate the both LaiPen instruments to the dark condition (see chapter 5.2).
3. Set both the instruments to single angle mode of measurement ***Setting > Angles > Single***.
4. For dual sensor mode it is essential that detectors of both instruments are set to same value prior measurement. Log the reference value with both instruments (instrument_1 and instrument_2)**.** Go to ***Main Menu > Measure > ARef*** and press ***SET***. After pressing ***SET*** online measurement of reference value is activated. Irradiance is continuously monitored. These values are not stored to internal memory of the device.
5. Use the displayed reference values from the instrument_2 to adjust calibration constant of the instrument_1 to achieve the same reference value as displayed on the instrument 2. Go to ***Settings > LAI Cal*** and by repeatedly pressing ***SET*** adjust the C value and the same reference readings (I value) appears on both instruments.
6. Set the instrument_1 in an open space for automatic logging of reference signal.
   6.1. Go to ***Main Menu > Settings > AutoRef*** to define the repetition time for automatic measurement on the instrument_1.
   6.2. Set a tripod in an open space (see chapter 4.2.1) and mount the instrument_1 to the tripod loosely, in horizontal (PAR measurement) or vertical (ALAI measurement) position.
   6.3. Set the instrument_1 to automatic mode of reference measurement. Go to ***Measure > AutoARef*** and press ***SET*** to start the navigation for obtaining zenith angle position of the LAI sensor. In case of PAR measurement go to ***Measure > AutoPRef*** and press ***SET***.
   6.4. Position the LaiPen vertically with the LAI sensor pointing up to the zenith or horizontally for PAR measurement. In case of measurement of ALAI transmittance avoid entering direct sunlight into the view restricting cup (see chapter and 4.2.2) during the process of measurement in sunny weather condition.
   6.5. Watch the display, tilt the instrument in left–right direction and in forward–backward direction to achieve the lowest angle for both axis angle eadings. This step can be sometimes tediuos since the correct position must be achieved in range of milimeters. After reaching the correct position tighten the LaiPen instrument to the tripod firmly.
   6.6. Press ***SET*** again. Reference values are automatically acquired and displayed in format “REF X = value”, where X is the measurement number.
7. In this step transmittance measurement with the instrument_2 under the canopy is described.
   7.1. Define position below the vegetation canopy for ALAI or PAR canopy irradiance measurement.
   7.2. Go to ***Main Menu > Measure > ALAI*** or ***Main Menu > Measure > PAR*** and press ***SET*** to activate online measurement of irradiance. Irradiance is continuously monitored; actual reading appears on the display. These values are not stored to internal memory of the device.
   7.3. Press ***SET*** again to obtain ALAI or PAR value, which are acquired automatically in the following procedure. First, internal inclinometer and acoustic beeping indicator are activated. Detailed readings of angle degrees to zenith direction appear on the display for both axis.
   7.4. Place the LaiPen vertically with the Lai sensor pointing up to the zenith. The acoustic indicator would change from low tone to high tone beeping when the current position of the instrument_2 is reaching angle close to the correct zenith angle.

7.5. Watch the display, tilt the instrument in left-right direction and in forward-backward direction to achieve the lowest angle for both axis angle readings. This step can be sometimes tedious since the correct position must be achieved in range of milometers.

7.6. Measurement proceeds automatically, when the correct position is reached. This is indicated by increased frequency of beeping after which beeping tone is interrupted. At the same time the display shows in first row number of measurements in format "ALAI (PAR) X" where X is the measurement number and in the second row the irradiance value in format "I = value". The readings are stored to LaiPen memory and the instrument switches back to continuous reading mode.

8. After each measurement the data is stored to the device internal memory and the instrument can be switched off by holding ***MENU*** button for 1 second safely without erasing data.
9. To return to the main menu press ***MENU*** repeatedly until ***Return*** is selected and then press ***SET***. Connect the instruments to computer and download the data as described in chapter 9.

5.5 Multiple Angle mode of Measurement

In this chapter protocol with single LaiPen instrument measuring irradiation in five zenith angles is described.

	Multiple angle mode is used for measurement only with the LAI sensor.

1. Switch on the instrument by holding ***SET*** for 1 second and set the actual date and time if necessary (***Main Menu > Settings > Time***).
2. Calibrate the instrument to the dark (see chapter 5.2).
3. Set the LaiPen (or make sure it is set) to multiple angle mode of measurement ***Main Menu > Settings > Angles > Multiple.***
4. If you want to use GPS device, turn it on and carry the device during all canopy measurements with the LaiPen device (see chapter 6).
5. Take reference measurement in an open space. In sunny weather condition avoid entering direct sunlight into the view restricting cup (see chapter 4.2.2).

5.1. Set ***Main Menu > Measure > ARef*** Press ***SET*** to activate immediate measurement of reference values. Irradiance value is continuously monitored, actual value appears on the display. Please note that these values are not stored to internal memory of the device.

5.2. Press ***SET*** again to start the navigation to acquire reference values. Reference values must be obtained in all five zenith angles of the LAI sensor subsequently. Internal inclinometer and acoustic beeping indicator are activated and all five subsequent measurements proceed automatically, when the correct position of individual angles are reached. The correct position from the target angle is indicated as 0^0 angle at both x and z axis with tolerance 5^0. Readings of angle degrees for current position of Lai sensor appear on the display for both X and Z axis. This step can become quite tedious since the correct position must be achieved in range of milometers.

5.3. Place the instrument in horizontal position, watch the display and tilt the instrument slowly in vertical direction while keeping the LAI sensor facing upward. The acoustic indicator would change from low tone to high tone beeping when the position of the instrument reaches angle close to the first target at 64°. Tilt the instrument to achieve the lowest angle for both readings (X and Z axis). Interruption of the high tone beeping and switching to low tone beeping indicates completion of measurement of the target value.

5.4. Watch the display and tilt the instrument slightly more vertically to achieve the lowest angle for both readings (X and Z axis). The acoustic indicator would switch from low to high tone when the position of the instrument is reaching angle close to the second target angle value (48°). Interruption of the high tone beeping and switching to low tone beeping indicates completion of measurement of the second value.

5.5. Repeat the previous step for the remaining three angles 32°, 16° and 0° (zenith angle).

	Neither target angle values (64^0, 48^0, 32^0, 16^0, 0^0), nor readings are shown on the display during measurement.

6. In the next step measurement under the canopy is described. Define position under vegetation canopy and start the ALAI measurement.
   6.1. Set ***Main Menu > Measure > ALAI*** Press ***SET*** to activate immediate measurement of reference values. Irradiance value is continuously monitored, actual value appears on the display. Please note that these values are not stored to internal memory of the device.
   6.2. Press ***SET*** again to start the navigation to acquire reference values. Reference values must be obtained in all five zenith angles subsequently. Internal inclinometer and acoustic beeping indicator are activated to obtain each zenith angle of the Lai sensor. All five subsequent measurements proceed automatically, when the correct position of individual angles are reached. The correct position from the target angle is indicated as 0^0 angle at both x and z axis with tolerance 5^0. Readings of angle degrees for current position of ALAI sensor appear on the display for both X and Z axis. This step can become quite tedious since the correct position must be achieved in range of milometers.
   6.3. Place the instrument in horizontal position, watch the display and tilt the instrument slowly in vertical direction while keeping the ALAI sensor facing upward. The acoustic indicator would change from low tone to high tone beeping when the position of the instrument reaches angle close to the first target at 64°. Tilt the instrument to achieve the lowest angle for both readings (X and Z axis). Interruption of the high tone beeping and switching to low tone beeping indicates completion of measurement of the target value.
   6.4. Watch the display and tilt the instrument slightly more vertically to achieve the lowest angle for both readings (X and Z axis). The acoustic indicator would switch from low to high tone when the position of the instrument is reaching angle close to the second target angle value (48°). Interruption of the high tone beeping and switching to low tone beeping indicates completion of measurement of the second value.
   6.5. Repeat the previous steps analogically for other three angles 32°, 16° and 0° (zenith angle).

	Neither target angle values (64^0, 48^0, 32^0, 16^0, 0^0), nor readings are shown on the display during measurement.

7. After completion of all intended measurements return to the main menu press ***MENU*** repeatedly until ***Return*** is selected and then press ***SET***.
8. After each measurement the data is stored to the device internal memory and the instrument can be safely switched off by holding ***MENU*** button for 1 second safely without erasing data.
9. Connect the LaiPen to computer and download the data (see chapter 9).

5.6 Example of Zenith Angle Measurement and Lai Calculation

1. Define measurement points for canopy measurement. The points can be arranged in a grid or transects to surpass vegetation cover inhomogeneity caused by different canopy gaps etc. A suitable layout of transects helps to fix the distance (e.g. three steps) between measurement points and proportionally characterize all the diverse parts in vegetation cover. An example of a suitable transect layout in homogenous vegetation cover planted in rows is shown in Fig. 11.
2. Measure the first reference value in an open space in zenith direction as described in chapter 5.6. All the following measurements (i.e. above- and below-canopy) will be done with the same method in zenith direction.
3. Measure ALAI irradiance below vegetation at each position of the transect course (see chapter 4). You can measure reference values in an open space anytime during the measurement (e.g. after completion of each transect measurement).
4. Take the last reference value in an open space.
5. After finishing the measurements download the data to computer using FluorPen software and export the data as described in chapter 9.4.

	Although the current version of FluorPen software automatically calculates ALAI transmittance when downloaded from the LaiPen to computer it fails to add the transmittance values to exported file.

6. Calculate ALAI transmittance according to equation $T = I / I_0$ (equation 1) from irradiance values, which you can obtain after opening the exported file in a spreadsheet software (e.g. MS Excel, see chapter 5). Calculate ALAI transmittance using the spreadsheets by dividing the exported iradiance values below the canopy (I) named "value" by reference irradiance values predicted for each time of canopy measurement (I_0) named "ref.". Each measurement is calculated separately as $ALAI_1 = value_1 / ref_1$, $ALAI_2 = value_2 / ref_2$, $ALAI_n = value_n / ref_n$, where n is the number of below-canopy measurements.
7. Calculate logarithm of transmittance values.
    a. In case of inhomogeneous cover calculate logarithm of transmittance in each canopy measurement point $\ln(ALAI_1)$, $\ln(ALAI_2)$, ... $\ln(ALAI^n)$. Then calculate the average value of all logarithms in the first transect T_1 as $\ln(ALAI^I) = [\ln(ALAI_1) + \ln(ALAI_2) \ldots + \ln(ALAI_{10})] / 10$. Proceed with remaining transects in a similar way.
    b. In case of homogeneous cover calculate an average ALAI transmittance for the first transect as $ALAI^I = (ALAI_1 + ALAI_2 \ldots + ALAI_n)/n)$ and then calculate logarithm of the average ALAI transmittance in the first transect T_1 as $\ln(ALAI^I)$. Proceed with remaining transects in a similar way.
8. Calculate the final average logarithm of ALAI transmittance in entire vegetation cover $\ln(ALAI) = [\ln(ALAI^I) + \ln(ALAI^{II}) + \ln(ALAI^{III}) + \ln(ALAI^{IV})]/4)$.
9. Nominate extinction coefficient *k* and calculate LAI by dividing the resulting value with k, thus: $LAI = (1/k) |\ln(ALAI)|$. With the most frequent value of extinction coefficient $k = 0.5$ the LAI would be calculated as $LAI = 2|\ln(ALAI)|$. For more information refer to chapter 3.1.

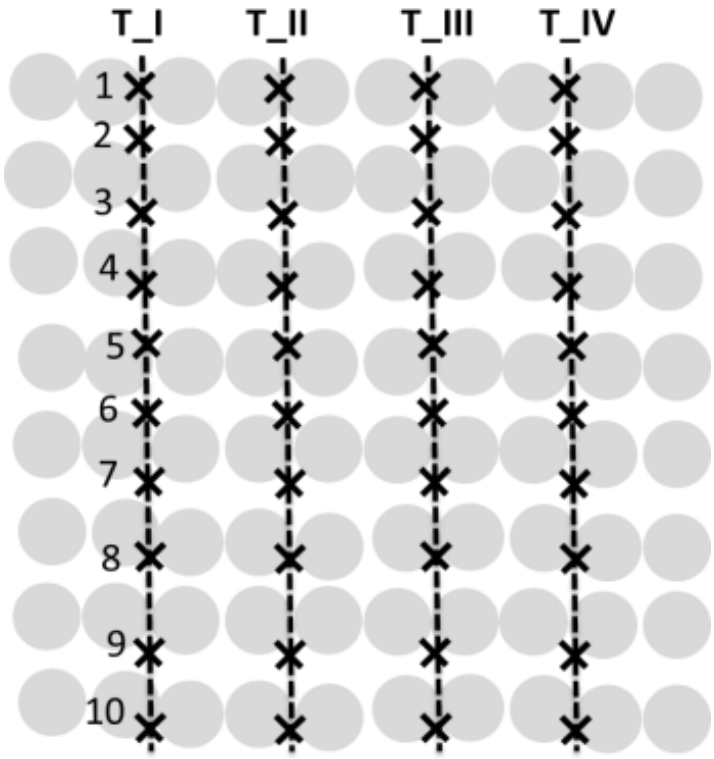


Fig. 11 Schematic drawing of transects (T) in vegetation cover.

Plants, which are planted in rows are represented by horizontal lines of gray spots. Each measurement point (✕) is indicated along transects (from T_I to T_IV). The first ten points in T_I are numbered 1✕ - 10✕. Note that transects are arranged perpendicularly to the rows of plants.

6 CONTROL MENU TREE

To switch ON the device, hold the SET key for 1 second. Use the control menu tree to perform the measurements. Use the ***MENU*** button to scroll through sequential menu options on the digital display. Use ***SET*** button to select an option indicated with the cursor position (>). The following diagrams describe the structure of the Menus (Fig. 12**Error! Reference source not found.** - Fig. 16) with all available options.
Switch OFF the device after use by holding the MENU button for 1 second.

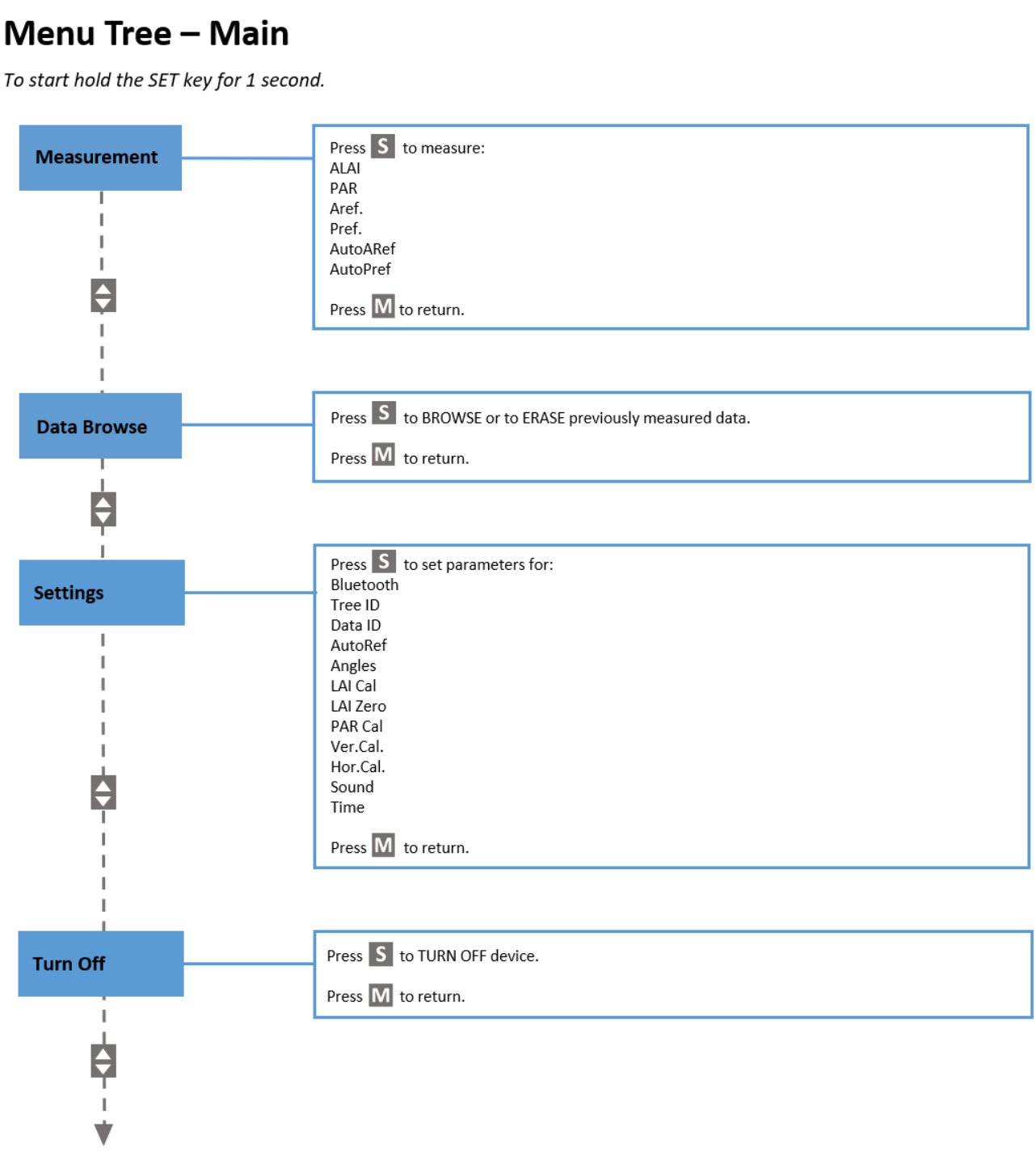


Fig. 12 Main Menu.

Measure Sub-Menu

Use the Measure Sub-Menu when measuring selected parameters.

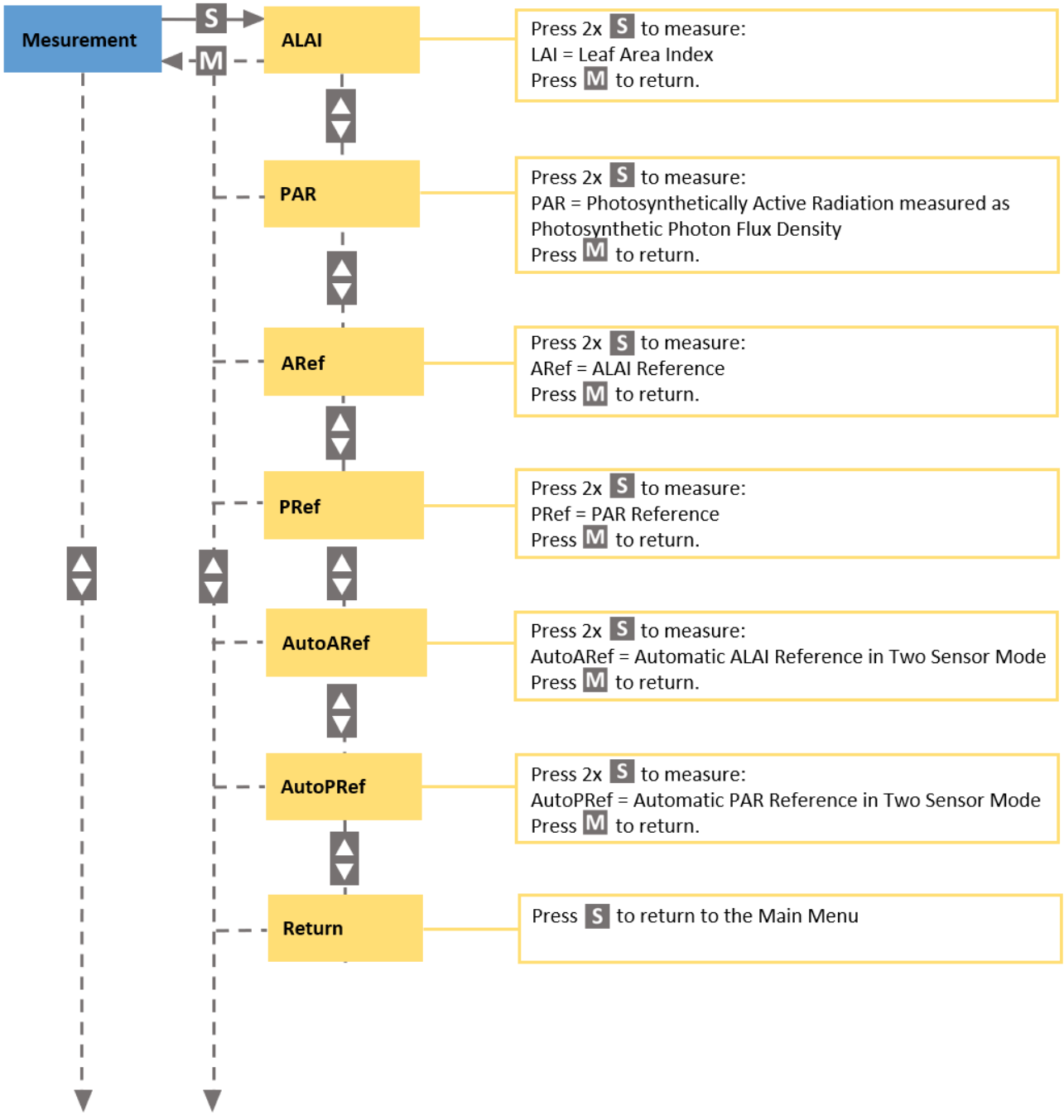
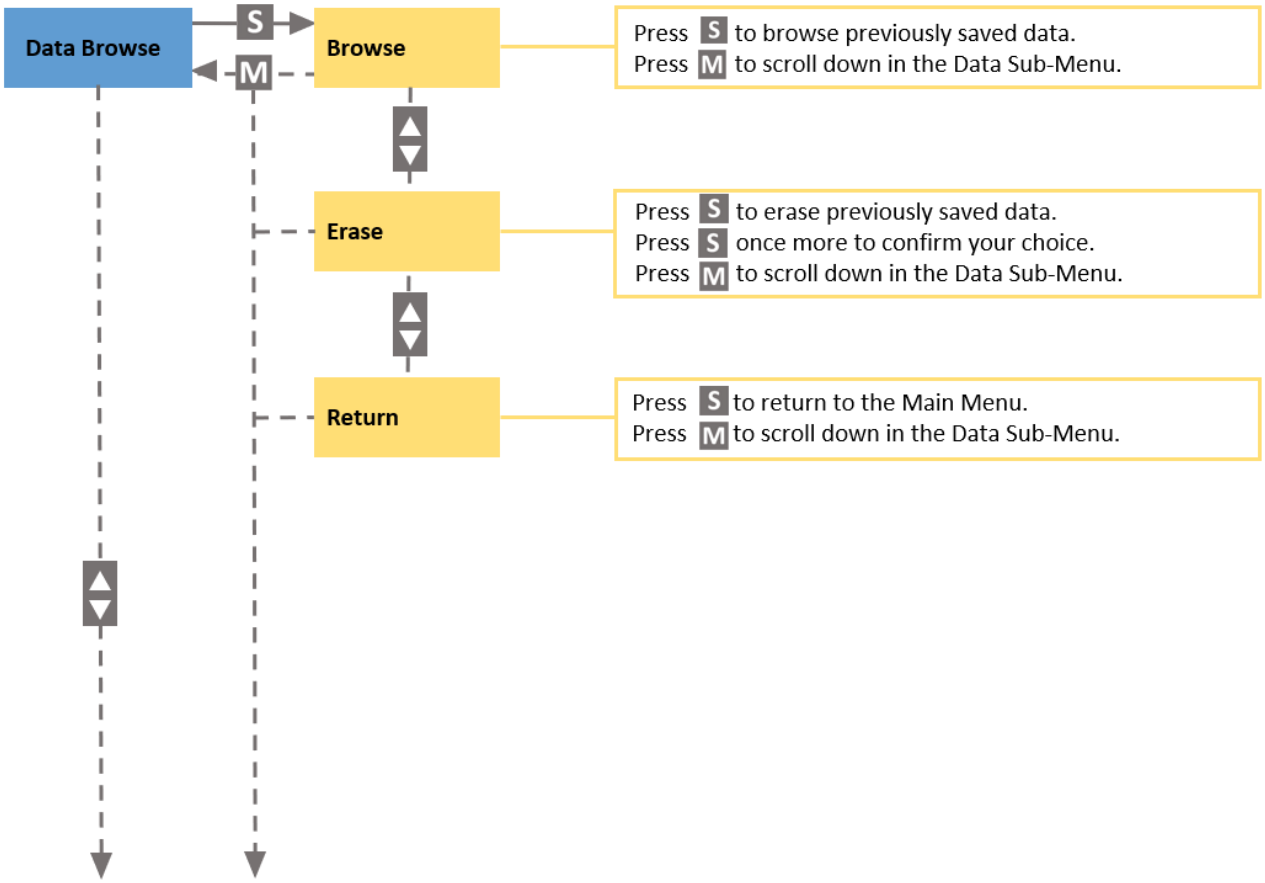


Fig. 13 Measure Sub Menu.

Data Sub-Menu

Use the Data Sub-Menu when browsing or erasing previously measured data.



IMPORTANT NOTE: Be aware that it is not possible to erase single data. **All stored data are erased!**

Fig. 14 Data Sub Menu.

Setting Sub-Menu – Part 1

Use the Setting Sub-Menu to set date, time and the sound mode or to calibrate parameters.

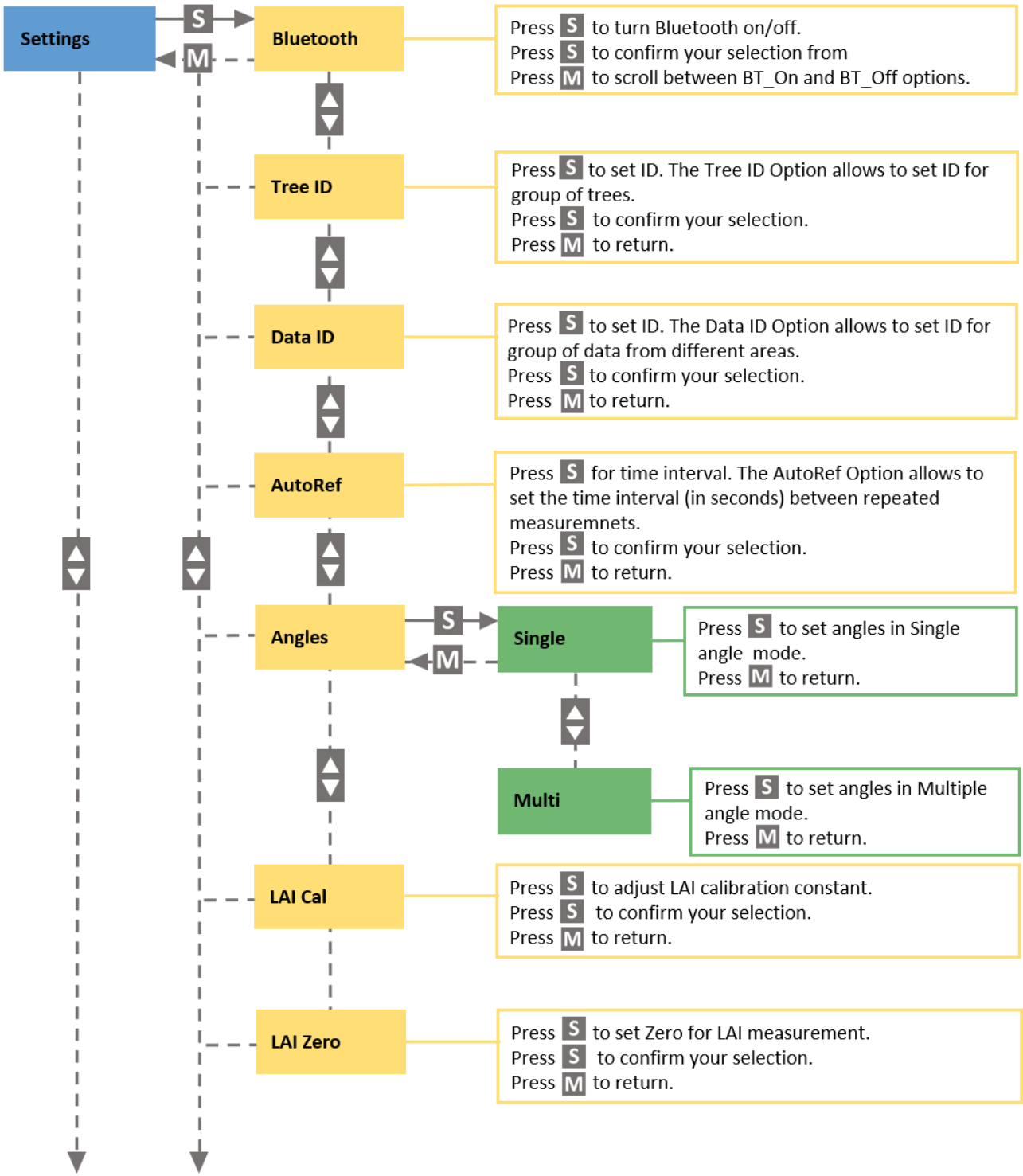


Fig. 15 Setting Sub-Menu-Part 1.

Setting Sub-Menu – Part 2

Use the Setting Sub-Menu to set date, time and the sound mode or to calibrate parameters.

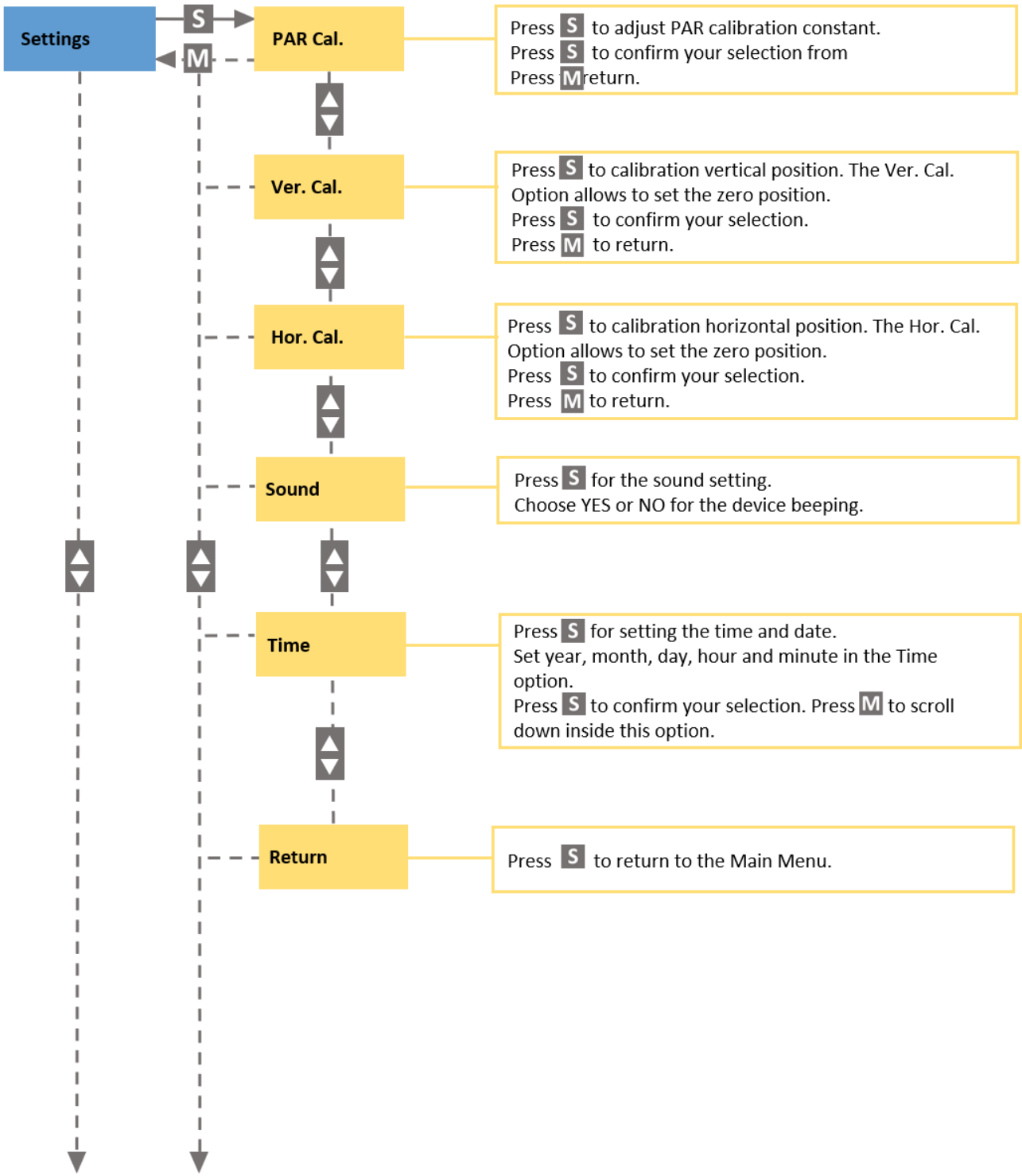


Fig. 16 Setting Sub-Menu-Part 2.

7 CONNECTING VIA USB CABLE

LaiPen comes with the USB cable that is required for charging of the Li-ion battery and can also be used for data transfer to the PC after completion of measurements. To connect the USB cable with the FluorPen device follow the picture instructions below. Please note that a lock in system is used to secure the USB cable to the LaiPen and extreme caution has to be used when setting up this connection to avoid damage to the cable pins.

⚠	When connecting the USB cable take extra caution to prevent damage to the cable connector pins. Ensure correct orientation of the cable as shown in the pictures below so the circled portion of the plug and the cable in photo A and B are perfectly lined up prior to pushing them together. Once this connection is achieved the cable may be secured in position by turning the metal cover of the cable and locking the cable in position.

To connect LaiPen with your computer please follow steps below:

Fig. 17 How to connect LaiPen with PC.

A) Connector of the FluorPen. B) The USB cable connector with pins. C – E) Place the cable horizontally and line up the red circled parts of the cable and the connector, plug in the inlet and screw the securing screw. F) Correct connection of the USB cable and Pen device.

Once the cable is securely attached to the LaiPen the other end may be connected to the USB port on a PC. The LaiPen **switches ON** automatically after connecting the cable to the PC. For the USB connection to be successful the USB driver and the FluorPen software need to be installed on the PC. Both may be found on the installation disk (USB driver folder) delivered with the device. Once the USB driver is installed the Device Manager in Windows will list the USB serial port in the device tree. The USB driver may also be downloaded from PSI websites www.psi.cz. Once the driver is installed correctly the connection between the LaiPen and the computer is initiated by selecting in the software on the computer **Setup > Device ID.**
For more information about FluorPen software see chapter **Error! Reference source not found.**.

8 CONNECTING VIA BLUETOOTH

The device can be connected to the PC via Bluetooth. Before setting up the connection ensure the following components are in place:

Bluetooth hardware installed on your PC and configuration software properly set up
The PC must have Bluetooth wireless technology, either built-in or through a Bluetooth card. Ensure that the PC's Bluetooth setting is in "discoverable" mode (meaning that it shows up when other devices search for nearby Bluetooth connections). Consult the user guide for

the PC or Bluetooth card to learn how to do this. The Bluetooth software that came with the PC, or the PC's Bluetooth card may need to be activated. This software varies by manufacturer. Please consult the PC's Bluetooth documentation for more information.

Bluetooth must be switched on and be visible on both devices

Ensure that Bluetooth is switched on both devices.

Enabling Bluetooth in the LaiPen device

- To enable Bluetooth in the LaiPen scroll to the Accessories menu (press the **MENU** key) and select Accessories by pressing the **SET** key. Then select Bluetooth On (press **MENU**, then turn it **ON** by pressings the **SET** key).

⚠	Keep in mind that the device turns off automatically after about 8 minutes of no action. Turning off the device also turns OFF the Bluetooth.

Starting Bluetooth Application on the PC

- On your PC select: **Start > Devices and Printers** or **Start > Control Panel > Hardware and Sound > Devices and Printers and start the Bluetooth**

Adding LaiPen device to computer

Select: "**Add a device**" to search for a new Bluetooth device. When found, start the pairing process. Please note that the FluorPen device does not display the verification number. The verification code is not important for the BT connection.

9 FluorPen Software

9.1 Software Installation

1. Copy the FluorPen software provided on the USB flash disk to your computer
2. Start the FluorPen program
3. When connecting the LaiPen device to the FluorPen software for the first time, proceed with registration of the FluorPen software (Fig. 18). Select: Help > Register and enter your serial registration number. The number is found in the text file on the USB flash disk drive shipped with the device. Confirm with the OK button.
4. Switch on the LaiPen device and enable Bluetooth or connect USB cable to the PC.
5. Ensure the PC and the device are properly paired (see chapter 7 and 8 for complete information on USB and Bluetooth pairing).
6. In the software select: Setup > Device ID (Ctrl+I). If properly connected, the message "Device: LaiPen" appears in the bottom left corner of the FluorPen window (Fig. 19). If the connection fails then the message "Device not found" appears. In this case check all the connectors or the Bluetooth pairing.

Fig. 18 Software registration

ℹ	Please note that it is not possible to download data without software registration.

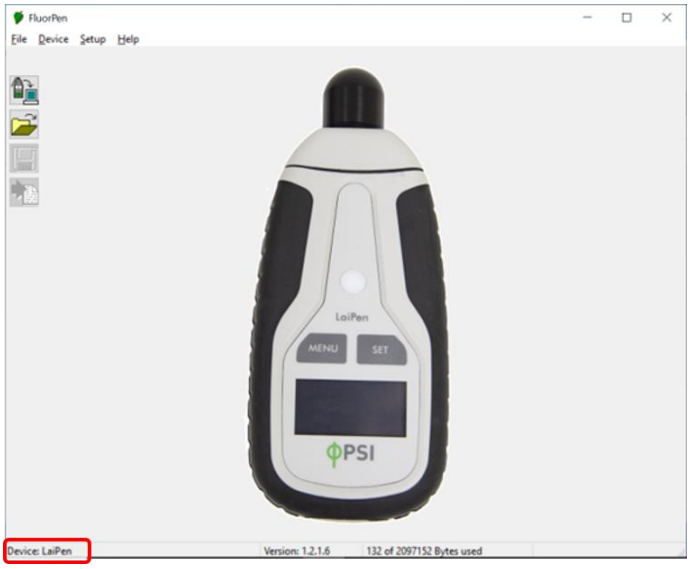


Fig. 19 Connecting LaiPen to software.

9.2 Menu and Icons Explanation

9.2.1 Main Menu

MENU: File (Fig. 20)

Load	Loads previously saved data files.
Save	Saves data to hard disc.
Export	Exports data in .txt format.
Export to JSON	Exports data in JavaScript Object Notation.
Close	Closes the current experiment.
Close All	Closes all running experiments.
Exit	Exits the program.

Fig. 20 Menu File.

MENU: Device (Fig. 21)

Download	Downloads data from the LaiPen to your PC.
Erase Memory	Erases data from the LaiPen memory.
Online Control	Settings sound and time.
Attach GPS File	Used for download data from GPS module.

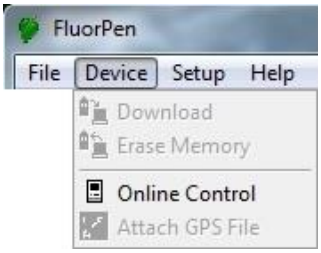


Fig. 21 Menu Device.

MENU: Setup (Fig. 22)

Device ID	Detects the connected device.
Update Firmware	Used for firmware updates.
Settings	Used for modification of the program settings.

Fig. 22 Menu Setup.

MENU: Help (Fig. 23)

About Offers basic information about the program.

Register Used for the FluorPen software registration.

Fig. 23 Menu Help.

Icon Explanation:

Download Downloads data from the LaiPen to PC.

Load Loads (opens) previously saved data files.

Save Saves data to local storage.

Export Exports data in .txt format.

9.2.2 MENU SETTINGS

MENU > Setup > Settings (Fig. 24)

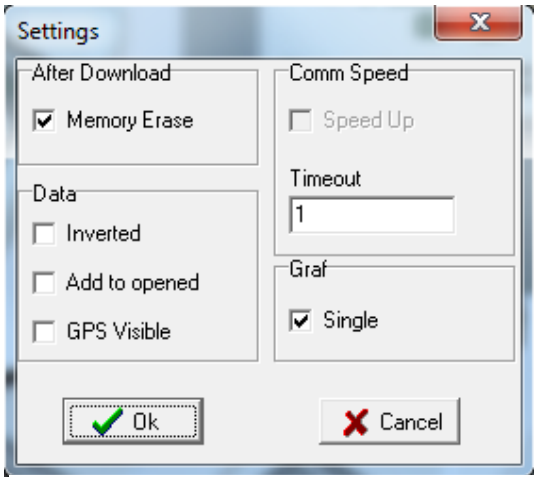


Fig. 24 Settings.

After Download – Memory Erase
If the box is checked the LaiPen memory is erased after each data download.

Data – Inverted
Not applicable to the LaiPen device LP110

Data – Add to opened
downloaded data are added to the open experiment. This is used when second device is used in dual sensor mode.

Data – GPS Visible
Not applicable to the LaiPen device LP110.

Graf – Single
Not applicable to the LaiPen device LP110

9.3 DATA DOWNLOAD AND VISUALIZATION

9.3.1 SINGLE SENSOR MODE

1. In the FluorPen software set the connection ***Setup > Device*** **ID** (Keyboard shortcut Ctrl+I). When connected, ***Device LaiPen*** appears on the bottom left corner of the FluorPen software main window.
2. Select: ***Device > Download*** or simply click the ***Download*** icon. The data table appears (Fig. 25)

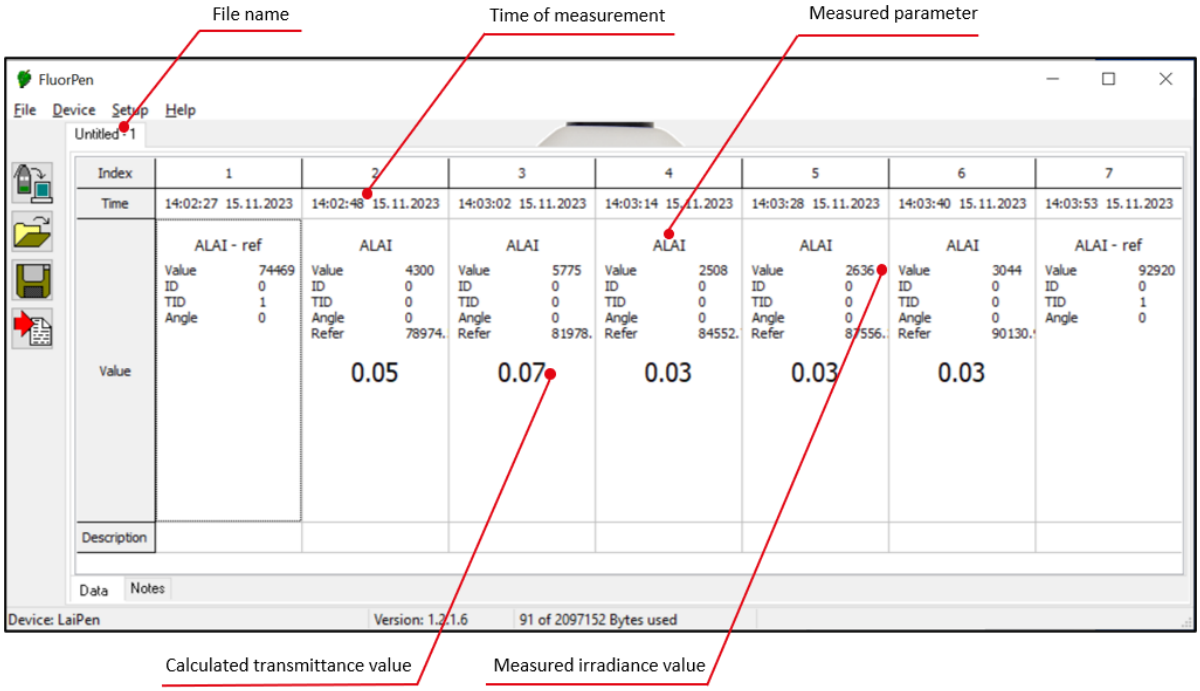


Fig. 25 Data viewing window description

Dual Sensor Mode: Data Management

1. In the FluorPen software open ***Setup > Settings***. The settings window appears (Fig. 26). Select the ***Add to opened*** option.
2. Connect instrument_1 to computer and select ***Setup > Device*** **ID**
3. In the main menu select ***Device > Download*** or simply click the ***Download*** icon**.** Data table with reference values appears.
4. Connect instrument_2 to computer and select ***Setup > Device*** **ID**.
5. In the main menu select ***Device > Download*** or simply click the ***Download*** icon**.** The data table with reference readings should now include canopy readings as well.
6. Save data or export the data for further processing

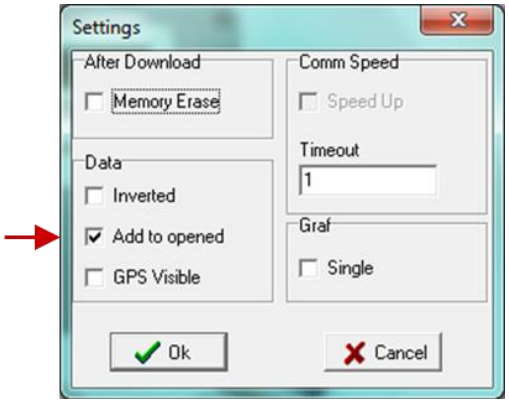


Fig. 26 Settings window: selecting the option Add to opened

9.4 Data Export

To **export** the measured and calculated data follow the next steps:

1. **Select *File > Export*** or click the ***Export*** icon.
   Export parameters window opens (Fig. 27). In the window flag the following checkboxes to select what data should be exported.
   - **Selected only** – when flagged only one measurement item selected by mouse click is exported
   - **Source data** – exports raw irradiation data
   - **Description** – exports data description if any
   - **Computed values** – exports PAR or ALAI transmittance values
2. Confirm with OK button (Fig. 27) and Export file opens (Fig. 28)

3. Select a path for local storage and type a filename

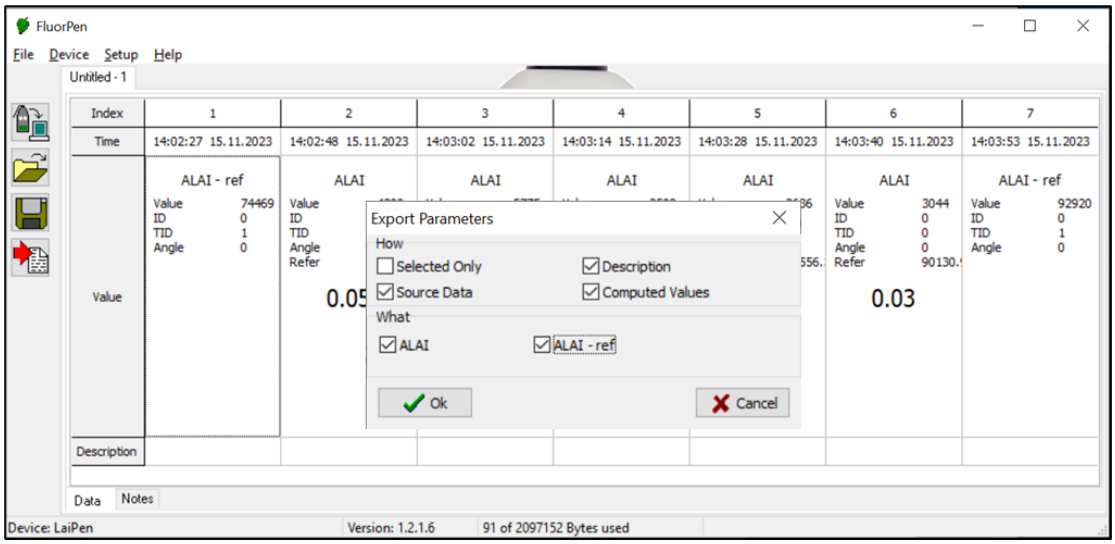


Fig. 27 Export Parameters window

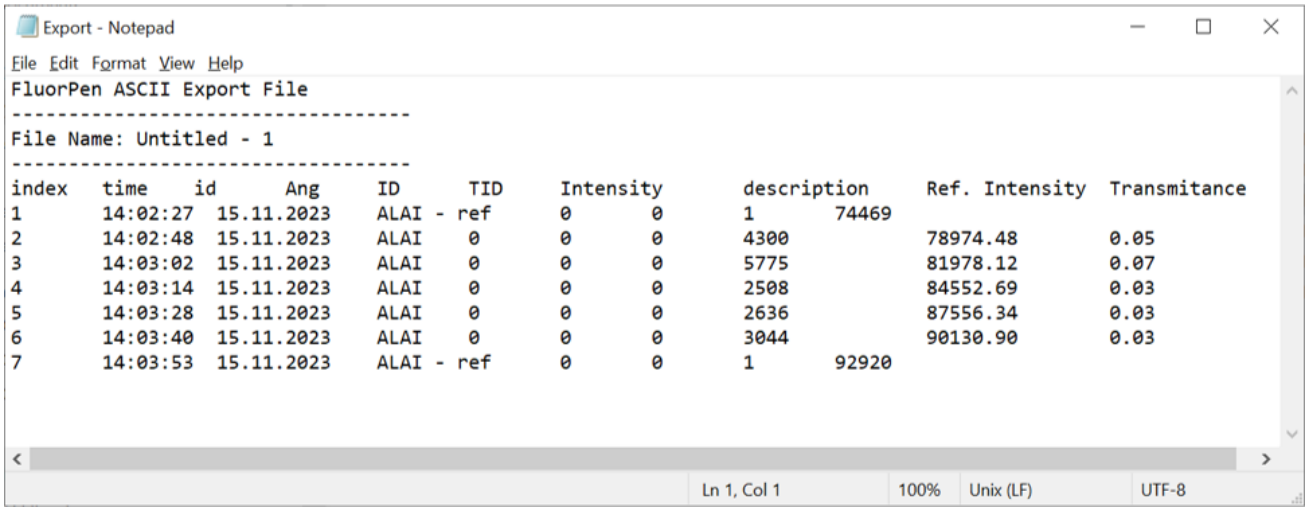


Fig. 28 Export – txt file

10 Firmware Update

⚠	All data in the LaiPen memory are erased during the firmware update! Before starting any firmware update, download all your data from the FluorPen memory to the computer!

1. Starting Update: Select Setup > Update Firmware From File (Fig. 29).

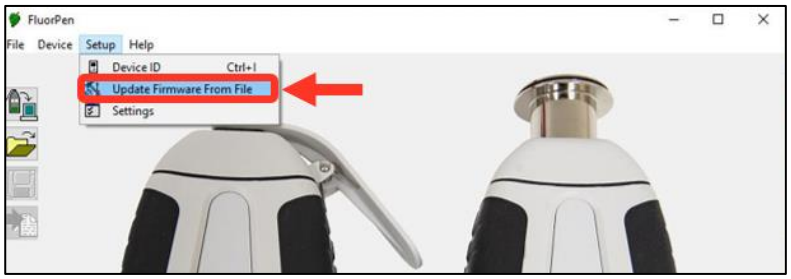


Fig. 29 Firmware Update.

2. Warning: Select **OK** to start update (Fig. 30).

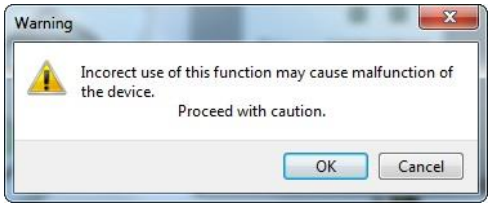


Fig. 30 Warning.

3. Selecting .**bxn file.** Find firmware update file (a binary file with the extension .bxn provided from PSI) and select **Open** (Fig. 31).

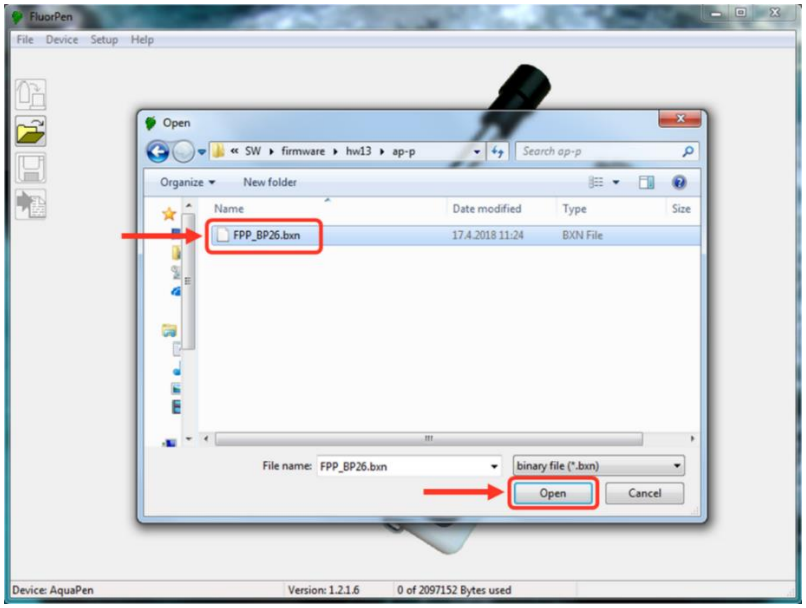


Fig. 31 Selection of the firmware file.

4. Finishing Upload
   - Select OK to start uploading of the update (Fig. 32).

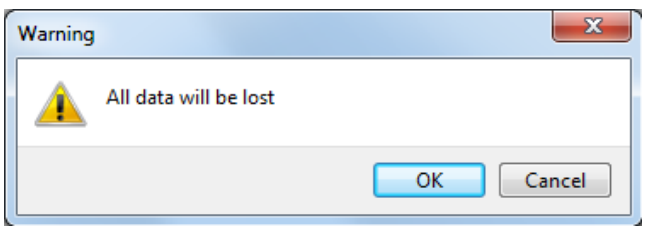


Fig. 32 Data loss warning.

- The bottom bar indicates the upload progress (Fig. 33).

Fig. 33 Firmware upload progress.

- Press OK to finish the upload (Fig. 34).

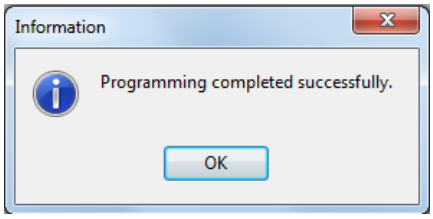


Fig. 34 Firmware upload finishing.

	The LaiPen memory is completely erased during firmware update. Before starting any software update, save your data from the LaiPen memory into your computer!

11 GPS MODULE

The new versions of the device (LP110) have integrated GPS module which can be turned on before the measurement. When ON all coordinates will be automatically paired with data collected from measurements.

	Before using the GPS module ensure the time and date in the LaiPen device is synchronized with the PC.

11.1 GPS OPERATION

1. Ensure the time setting on the LaiPen device is correct (**Settings > Date & Time)**
2. Switch ON the GPS module on the device by the following steps:

   - Select **Accessories > GPS > Status**
   - Press **SET** to confirm.
   - **Starting GPS message appears on the display**
   - Wait until position is tracked with GPS. When position is tracked **the** GPS icon changes as is shown in Fig. 35

Fig. 35 GPS icon.

The icon of GPS activation is displayed differently based on status of receiving satellite signal (left: failure, right: correct tracking)

3. If the status does not change to signal reception (the icon on the display does not change) then proceed to **Accessories > GPS > Location** and manually map the GPS by pressing SET. **GPS Acquisition** message appears followed by coordinate values. If the GPS module has difficulties with position tracking, a message **GPS not locked** appears. It may be necessary to take the device into a location that is easily accessible by the satellite (clear sky view) and repeat the process.
4. When successfully activated proceed to the measurement step.

	For prompt determination of the coordinates use the option Accessories > GPS > Location.

	The device needs a clear view to the sky to acquire satellite signal. Keep in mind that the LaiPen turns off automatically after about 8 minutes of no action. Turning off the LaiPen always turns off GPS module.

11.2 DATA DOWNLOAD

1. Connect the device to the PC.
2. **Download Data** from the LaiPen:
   - Start FluorPen program and identify the LaiPen device with the software: **Setup > Device ID (Ctrl+I).**
   - Download data from the LaiPen to your PC by clicking the download icon.
   - When measured with activated GPS module GPS coordinates are downloaded and displayed automatically (Fig. 36)

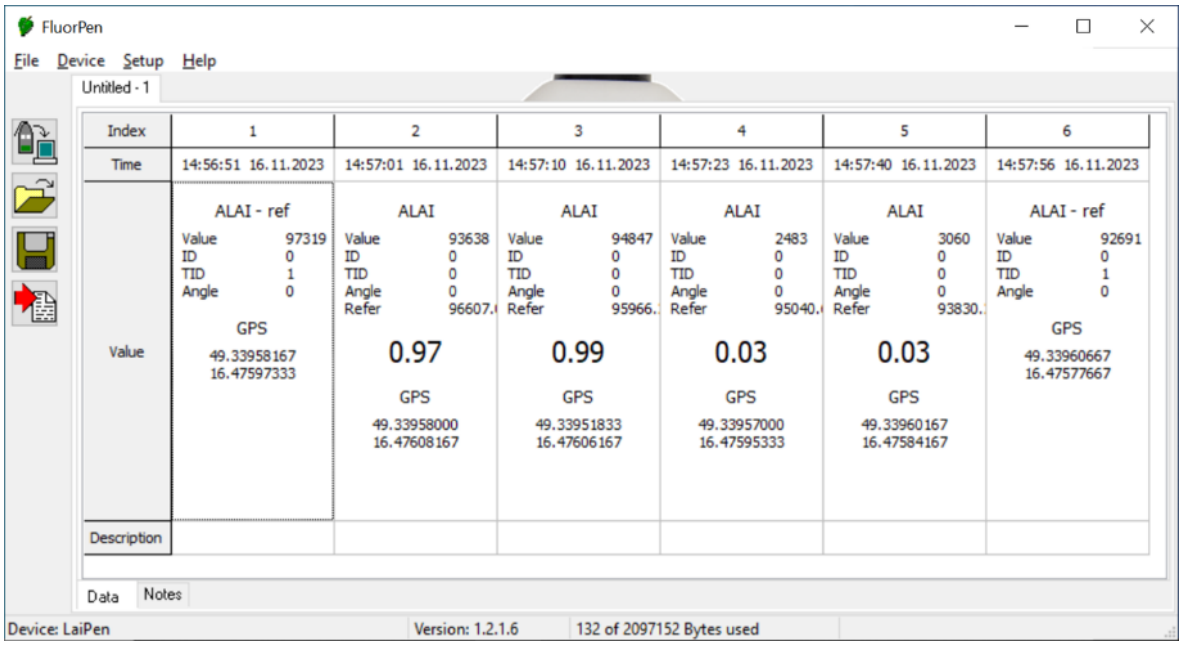


Fig. 36 Data in FluorPen window can contain GPS coordinates

12 Warranty terms and conditions

- This Limited Warranty applies only to the LaiPen LP 110 device. It is valid for one year from the date of shipment.
- If at any time within this warranty period the instrument does not function as warranted, return it and the manufacturer will repair or replace it at no charge. The customer is responsible for shipping and insurance charges (for the full product value) to PSI. The manufacturer is responsible for shipping and insurance on return of the instrument to the customer.
- No warranty will apply to any instrument that has been (i) modified, altered, or repaired by persons unauthorized by the manufacturer; (ii) subjected to misuse, negligence, or accident; (iii) connected, installed, adjusted, or used otherwise than in accordance with the instructions supplied by the manufacturer.
- The warranty is return-to-base only and does not include on-site repair charges such as labor, travel, or other expenses associated with the repair or installation of replacement parts at the customer's site.
- The manufacturer repairs or replaces faulty instruments as quickly as possible; the maximum time is one month.
- The manufacturer will keep spare parts or their adequate substitutes for a period of at least five years.
- Returned instruments must be packaged sufficiently so as not to assume any transit damage. If damage is caused due to insufficient packaging, the instrument will be treated as an out-of-warranty repair and charged as such.
- PSI also offers out-of-warranty repairs. These are usually returned to the customer on a cash-on-delivery basis.
- Wear & Tear Items (such as sealing, tubing, padding, etc.) are excluded from this warranty. The term Wear & Tear denotes the damage that naturally and inevitably occurs as a result of normal use or aging even when an item is used competently and with care and proper maintenance.

13 References

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14 List of Figures