ArborSonic 3D Manual

Fakopp Kft.
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WARNING! Special care needs to be taken at all times. Although the software tries to over-estimate the risks, the computation of the safety factor contains simplifications and even the input data might be disrupted. You are solely responsible for ensuring that the System is appropriate for the use you put it to, and you understand that it is only one part of what is needed to assess the health of trees. Please understand that the System is just one tool to be used, along with your experience and training in assessing these living organisms, that the System cannot be relied upon as the sole source of evaluations, and that all hardware and software is subject to failure or misuse.

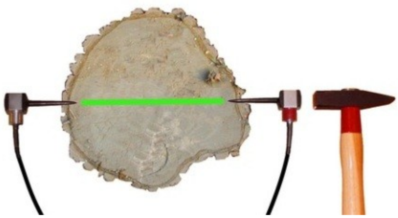
Introduction

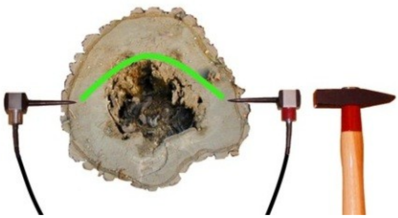
Urban tree stability is a critical concern for safety. Diseased and unstable trees pose significant risks and liabilities for municipalities, making assessments essential.

Acoustic tomography helps detect internal voids or decay within tree trunks, which can be used to estimate the force required for trunk breakage, and the safety of the tree at high wind speeds.

Principle of operation

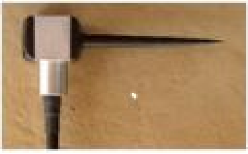
- Several Sensors are placed around the trunk, which are coupled to the tree by steel nails.
- Each Sensor is tapped by a hammer.
- The unit measures the travel-time of the sound wave generated by the hammer tap between the sensor that was hit and all other sensors.
- If there is a hole, then the sound waves have to pass around the hole and therefore it takes a longer time to reach sensors on the opposite side.





Hardware

Parts of the system



SD02 Piezo Sensors

Amplifier Boxes

Battery Box (gray) containing the Bluetooth transmitter

SD02 long sensors

Sensor remover

Link cables

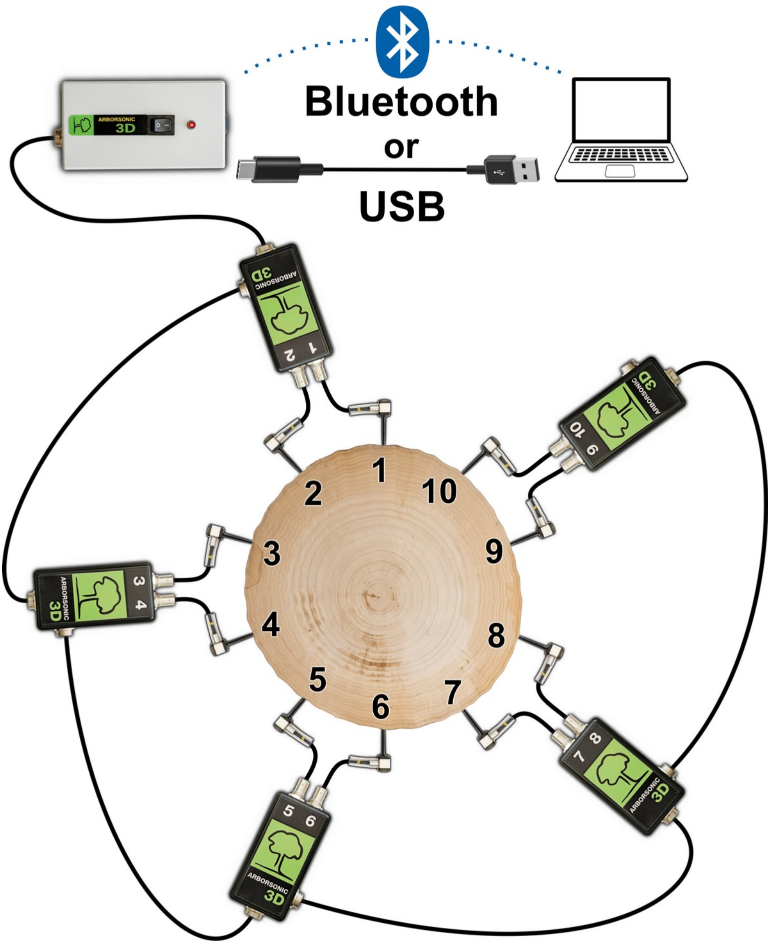
Case

Other components

- Tape measure
- Steel and rubber hammers

- Caliper (separate product)

Setup



- Drive the Sensors into the trunk, perpendicular to the direction of the growth in a counter-clockwise order as seen above.
- Connect the Sensors to the Amplifier boxes.
- Connect the Amplifiers in a line. The side connector goes to the bottom connector of the next box.
- Connect the Battery Box to an Amplifier on any end of the line.
- Establish cable or Bluetooth connection to the PC

Handling the sensors

Maintenance

- Always keep the nails, sensor head and the hammer clean, because dirt influences the coupling and time reading.
- The numbers on the sensors are just decoration, you can change them freely, however the numbers on the amplifier boxes are important.

Fixing

- Select the height that looks the weakest based on visual inspection (fungi fruiting body, mechanical damage, visible decay, ...)
- Use the rubber hammer to fix the sensors
- The sensors need to go through the bark and into the wood
- Good coupling between the nail and the wood is essential. The coupling is good if the sensor head can't be rotated with 3 straight fingers. If the sensors can rotate additional hammering is needed to couple the sensors well.
- The sensors need to be in intact wood material, not in decayed material.
- The software requires the penetration depth (PD parameter on the Sensor Geometry tab) of the sensors. This parameter is very important in case of small diameter trees.
- The sensor nails need to point to the center of the trunk
- The sensors need to be placed in the same plane. However, this plane doesn't necessarily have to be horizontal. The plane should be perpendicular to the fiber direction. In case of tilting trees, the plane should be tilted as well.

Measurement

- Use the steel hammer for generating the readouts by tapping on the sensor heads.
- Remove the tape measure before tapping because it may cause an acoustic short-circuit.
- Always tap on the center of the sensor head in the nail direction. If you accidentally tapped the side of the sensor, remove the data and tap again.
- Tap with consistent, uniform strength. Apply more power for larger trees.
- Tap the sensor with a loose wrist. Allow the hammer to bounce back.

Sensor removal

- Disconnect the sensor cable from the amplifier box. Then disconnect the cables.
- Rotate and pull the sensor in the line of the nail direction.
- Do not bend the nails while pulling. Do not apply sideways force.
- Use the removal tool if necessary.

Amplifier boxes

- When building up, first fix the sensors, then the amplifier boxes and finally the link cables
- Make sure to apply correct connector orientation when connecting the link cables. Don't force them.

- Amplifier numbering is essential. Don't cross the cables because it will mess up the measurement.
- Connect the bottom connector of an amplifier box to the side connector of the next amplifier box.
- Never move the sensors with attached amplifiers because it may damage the cable connectors.
- To disassemble, first remove the cables then the amplifiers and finally the sensors.

Battery Box

- Contains the 9V battery and the Bluetooth transmitter.
- Keep the Battery Box turned off while connecting the Amplifier Boxes.
- The Battery Box can be connected to any amplifier box.
- Make sure to apply correct polarity when changing battery.
- Any regular or rechargeable 9V battery can be used.
- The LED blinks for 5 seconds after turning on. This is the time required for the Bluetooth module to warm up.
- If the battery is low, the LED will keep blinking.
- The battery should be charged well (8V is the recommended minimum, it can be checked during measurement on the Time Data tab in the program, next to the green area indicating the used COM port).
- It is recommended to turn on the battery box only for the measurement (and keep it turned off during the rest of the time).
- The Bluetooth connection drains the battery faster than the cable connection.
- The battery should be in the proper position.

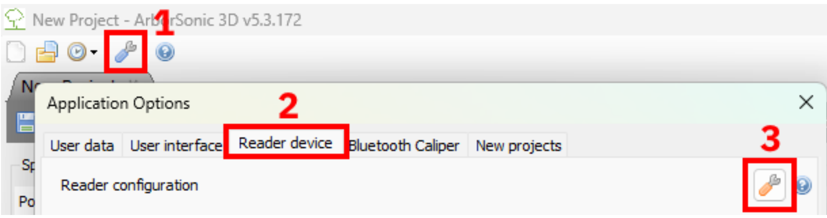
Software

Connecting to devices

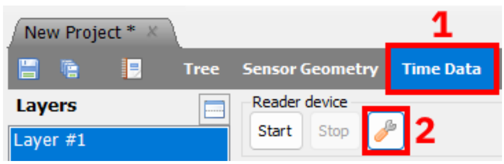
The ArborSonic3D software connects to the battery box either wirelessly using Bluetooth, or through a USB cable. The Bluetooth Caliper is only able to connect wirelessly. In both cases the software needs to be made aware of the exact device you wish to use before measurements may be taken. You should only need to take this step once when connecting wirelessly, though for USB connections you may have to repeat it if you change the port you plug the cable into.

Opening the Battery Box selector

The Battery Box to be used is selected in the *"Reader configuration"* dialog. This dialog may be found through the *"Application Options"* window.

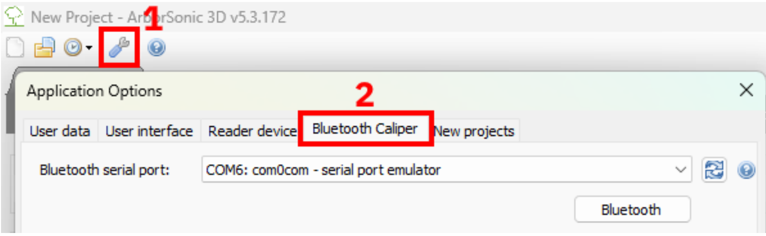


Alternatively the *"Time Data"* panel also has a button for it.

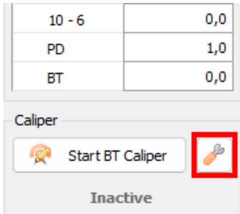


Opening the Bluetooth Caliper selector

The Caliper is selected in the *"Application Options"* window.



Alternatively there is a button for it at the bottom of the *"Sensor Geometry"* panel.

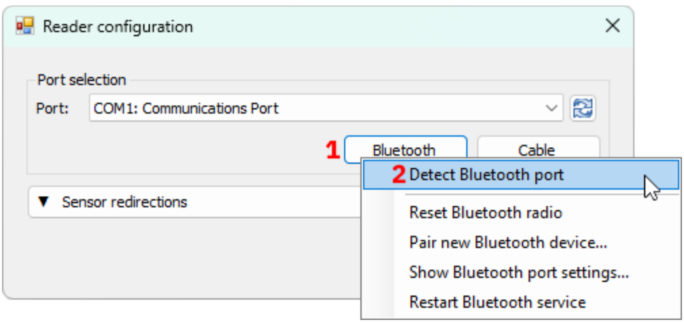


Automatic Bluetooth device selection

The software can attempt to automatically detect your device. This works well if there is only one Battery Box/Caliper nearby that is turned on.

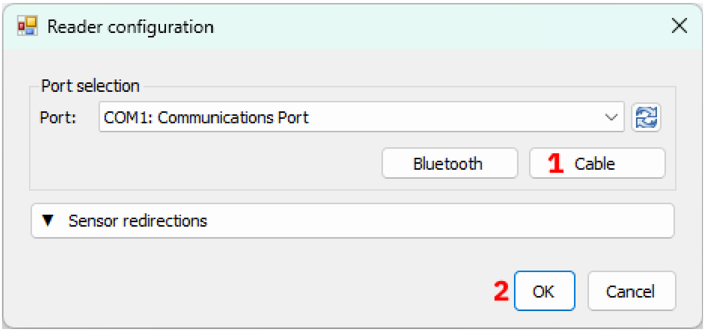
If you have an older device that uses Bluetooth Classic and is unpaired with the current computer, then please follow the steps to pair it in the Manual Bluetooth Classic device selection section before continuing here.

Click the *"Bluetooth"* button, then the *"Detect Bluetooth port"* menu item to select the device, the *"OK"* button to accept the selection.



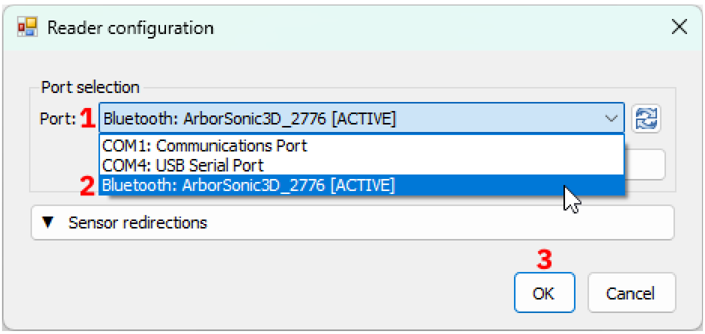
Automatic USB Battery Box (cable) selection

The software can attempt to automatically detect your device. Only one Battery Box USB cable should be connected to the computer. Simply click the "Cable" button to select the device, then the "OK" button to accept the selection.



Manual Bluetooth Low Energy (BLE) device selection

All recent ArborSonic3D and Bluetooth Caliper devices connect wirelessly using BLE.

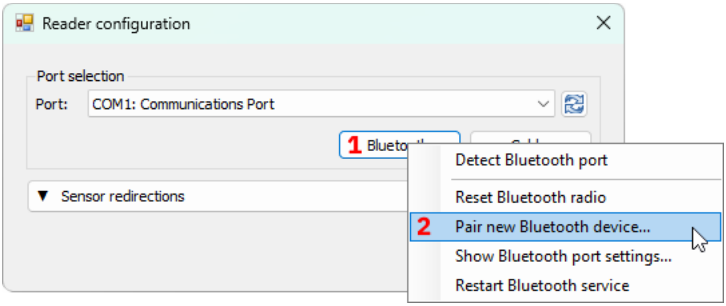


- Ensure that Bluetooth is turned on in Windows, then turn on the device.
- The device will appear at the bottom of the list with a *"Bluetooth:"* prefix.
- Battery Box devices contain *"ArborSonic3D"* in their names, while Bluetooth Calipers contain *"Caliper"*.
- Devices recently seen have the *"[ACTIVE]"* suffix.
- Click on the name of the device, then on the *"OK"* button.

Manual Bluetooth Classic device selection

Older Battery Boxes and Calipers connect wirelessly using Bluetooth Classic. Unlike BLE, such devices need to be paired with your computer before they appear in the list, however you should only need to do so once per computer.

To start pairing, click on the *"Bluetooth"* button and then select the *"Pair new Bluetooth device"* menu item.



This opens a Windows dialog. Unfortunately this dialog looks different various versions of Windows. Ensure that Bluetooth is turned on, then click the button for adding a new device.

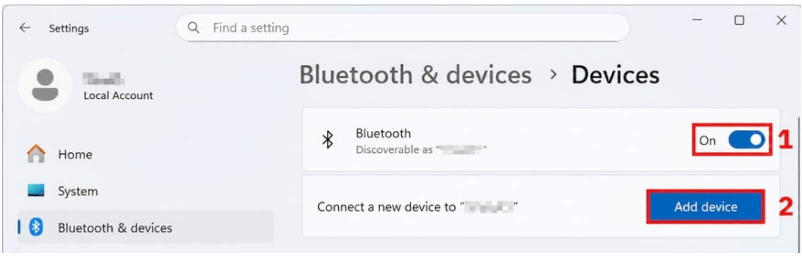


Figure 1: Windows 11 - adding Bluetooth device

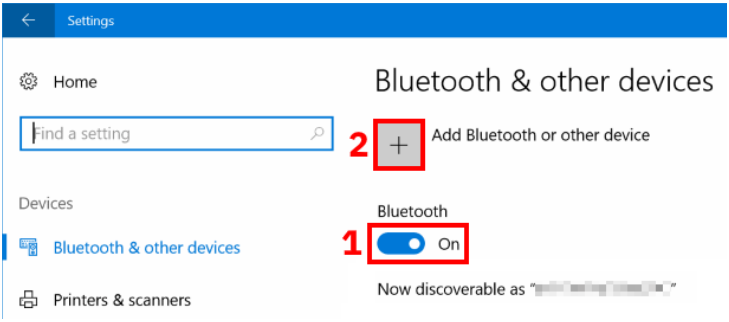
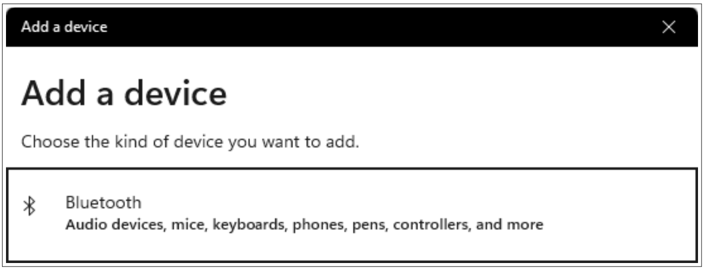
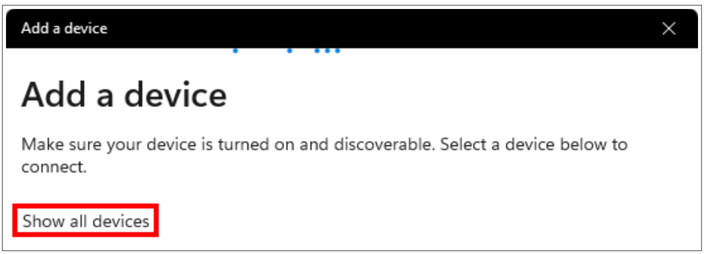
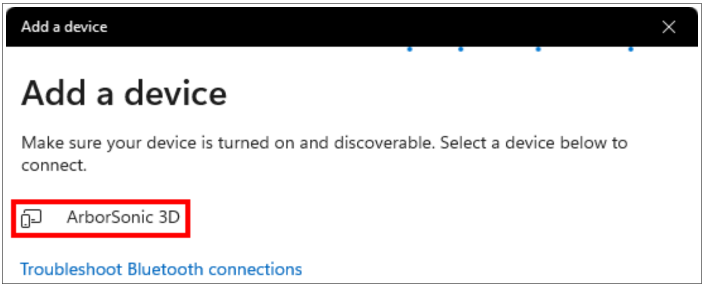


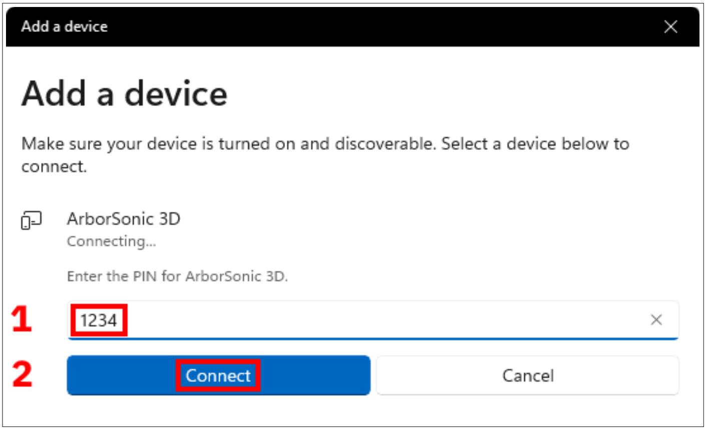
Figure 2: Windows 10 - adding Bluetooth device

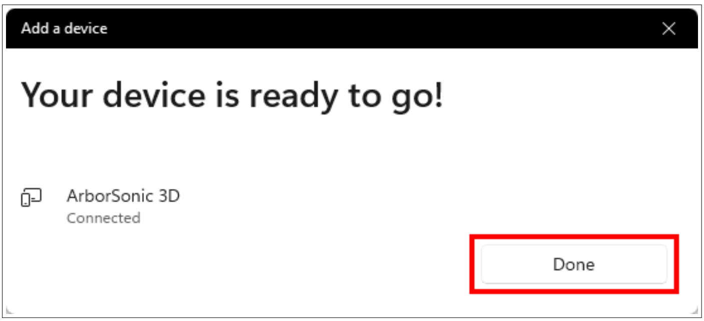
Select “Bluetooth” and “Show all devices”, make sure the the device is turned on and it’s name should appear in a few seconds (may sometimes take 20-30 seconds). Click on the name and if requested, enter *1234* as the PIN code. Wait for the connection to finish and close the window.



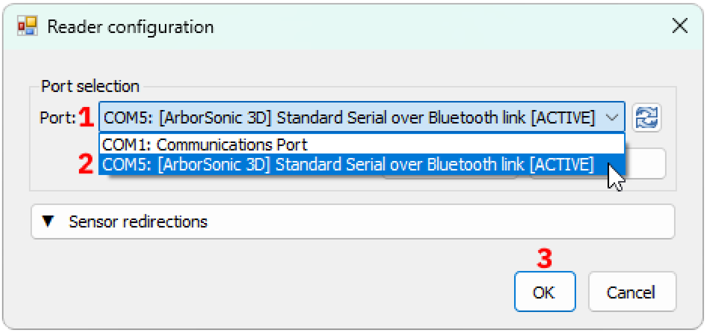








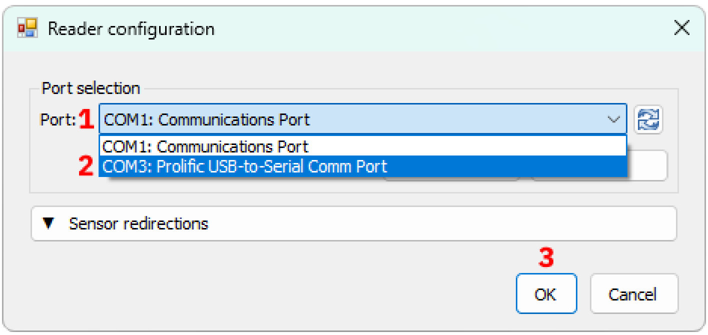
Return to the ArborSonic3D application. You should now see a “COM” port for the device added:



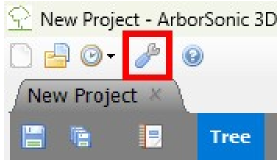
- The name of the paired device will appear in brackets, after a *"COM"* prefix.
- Battery Box devices contain *"ArborSonic 3D"* in their names, while Bluetooth Calipers contain *"Caliper"*.
- Devices recently seen have the *"[ACTIVE]"* suffix, though it might take 10-20 seconds to detect a device.
- Click on the name of the device, then on the *"OK"* button.

Manual USB Battery Box (cable) selection

- When the USB cable is plugged into the computer, a COM port is automatically created. This may take a couple seconds.
- Note that the COM port changes depending on which USB port you plug the cable into. If you change the port, you will likely have to select the device again.
- There is no *"ArborSonic 3D"* in the name or an *"[ACTIVE]"* flag for USB cables. The right COM port will instead have the *"Prolific" and "USB"* words in it's name, for original USB cables received from Fakopp Kft.

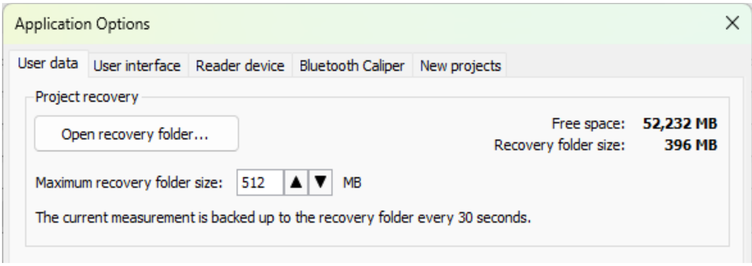


Application Settings



Global settings which apply to the entire application, including all projects opened or created, may be viewed and modified using the blue wrench icon at the top-left of the main window.

User data



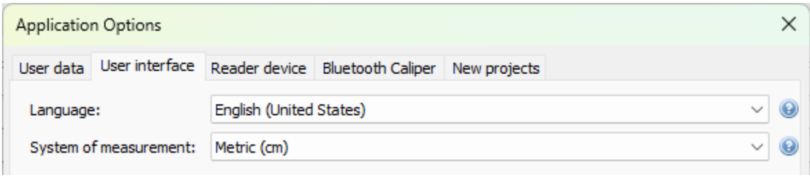
The application periodically saves copies of the currently edited projects. In case of data loss (e.g. computer power loss, damaged or lost files, ...), the *"User data"* tab may help recover your projects.

The *"Open recovery folder..."* button opens the folder where the project copies can be found. File names start with the date and time the copy was created (year-month-day_hour-minute-second). The file names also end with the name of the project file that was copied, except for copies of unsaved projects which only have a date and time.

You can open these projects as usual, by double-clicking on them. Projects opened from the recovery folder are copied to the user's *Documents* folder, so that they are easier to find in the future.

Please note that these recovery projects are not stored indefinitely: they are automatically deleted (oldest first) when the total size of the recovery folder reaches the size specified in *"Maximum recovery folder size"*. The current size of the recovery folder is displayed next to *"Recovery folder size"*. The total available free space on the drive is displayed next to *"Free space"*.

User interface



On the *"User interface"* tab the language and measurement system may be changed. Changing the language does not change some of the text within projects previously created (e.g. project or layer names, tree properties).

At the bottom of this tab there is an option to *"Disable hardware graphics acceleration"*. This may help resolve graphics driver errors (especially on *"Sensor geometry"* and *"Tomograms"*) when the application is next opened, but should be left unchecked otherwise.

Reader device

The *"Reader device"* tab is used to configure the communication with the ArborSonic 3D battery box.

- The "Reader Configuration" button  opens the same window as the same button on the Time Data page of the software. This window is responsible for selecting the COM port which is explained in the "Establishing connection to the Battery Box" section. The channel mixer tool lets you assign different numbering for the physical channel numbers as printed on the Amplifier Boxes. This is useful if you lose one of the boxes, let's say 5-6, but still want to perform measurements with 8 sensors using boxes 1-2, 3-4, 7-8, 9-10. (Detailed in chapter Testing and Troubleshooting.)
- Port diagnostics  is a tool that is useful for monitoring the raw data received from the device. It opens all the ports and listens to any data that is received. Using the Save button the data can be saved to an external file.

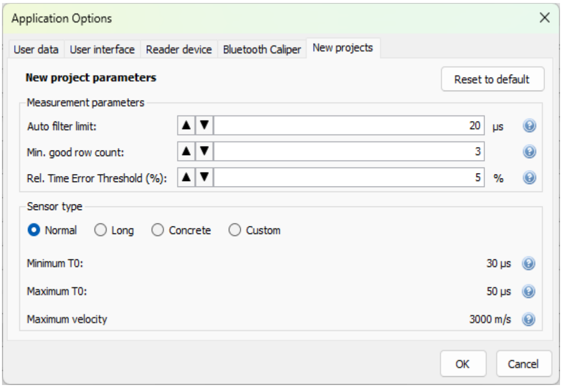
Bluetooth Caliper

The *"Bluetooth Caliper"* tab is used to configure the communication with the Bluetooth Caliper, if you have one.

New projects

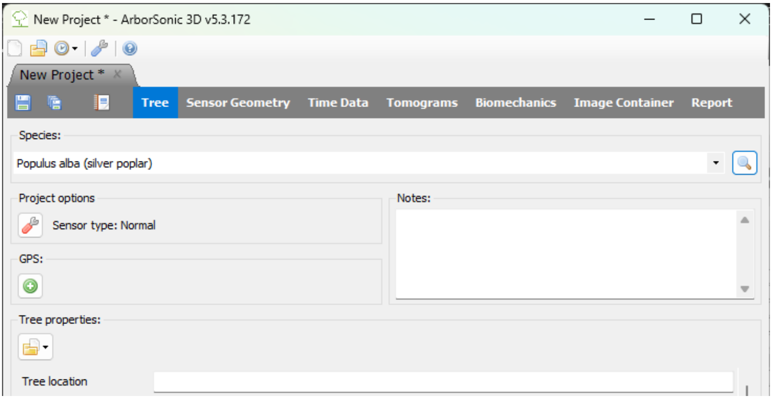
The *"New projects"* tab contains the initial settings used when a new project is created, starting with the next new project created after the OK button is clicked.

Note that project settings will override what is shown here. These settings merely help you avoid having to manually modify every new project to your preferred options.



- **Reset to default:** Overwrites all settings on the *"New projects"* tab with the defaults.
- **Auto filter limit:** Determines the limit of acceptable variance of valid measurements, per sensor.
- **Min. good row count:** The minimum number of good measurements required for each sensor. The application will indicate missing hits on the "Time Data" panel for sensors without this many hits.
- **Rel. Time Error Threshold (%):** Values in the time matrix on the *"Time Data"* panel are shown as red, if the relative error exceeds this limit.
- **Sensor Type:** The type of sensors attached to the amplifier boxes. The *"Custom"* sensor type allows manually specifying a few more parameters:
  - **Minimum/Maximum T0:** Clamps the calculated *"Time correction"* value shown on the "Time Data" panel. The effects of these parameters are out of the scope of this manual; they should not be modified unless requested by Fakopp support.
  - **Maximum velocity:** The upper limit of velocity values on the *"Tomograms"* panel.

Tree



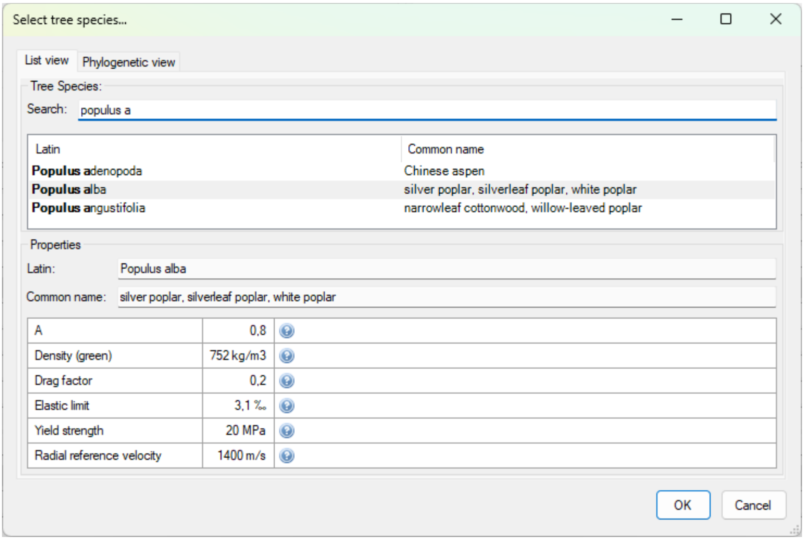
The “Tree” tab is used to specify the species, location and observations of the tree being measured. Only the tree species is a required parameter, other options may be ignored.

Current and recent tree species

The species of the tree is indicated and may be modified using the *“Species:”* box.

- The button with the magnifying glass opens a new window where a species may be searched for.
- The drop down box can be used to select a recently used species.

Tree species search window



The window allows searching a database of over 3000 tree species.

Species properties

The bottom half of the window shows the properties of the tree species selected in the top half:

- **A:** The ratio of tangential and radial sound velocity for the species (Vt / Vr)
- **Density (green):** The average density of the tree.
- **Drag factor:** Drag coefficient is a dimensionless quantity quantifying the resistance of the tree to wind. A lower drag factor indicates smaller aerodynamic drag.
- **Elastic limit:** The maximum relative displacement before the onset of permanent deformation in the material. The unit is per mille (1‰ = 0.1%)
- **Yield strength:** The stress corresponding to the yield point at which the material begins to deform, in megapascals.
- **Radial reference velocity:** Typical stress wave velocity in the radial direction of the tree trunk.

Species views

- **List view:** While typing the Latin or common name of the species, the list below will be filtered to only show matching species from the database. Select a species and click *"OK"*, or simply double-click the species to start using it.
- **Phylogenetic view:** Shows a tree based representation of all tree species. Typing the name of the species jumps to the location of the first match, and other matching species may be viewed by clicking the *"Next [F3]"* button, or pressing the F3 key. Click *"OK"* once the desired species is selected.

On either tab the bottom of the window shows details of the selected species.

Project options

The *"Project options:"* box indicates the type of sensor being used, as well as any parameters that are different from to the default values. The wrench button may be used to modify the parameters of only this project. The parameters are the same ones described in: Application Settings / New projects. Other than verifying that the *"Sensor type"* and *"Min. good row count"* parameters are correct, editing these parameters is not usually needed.

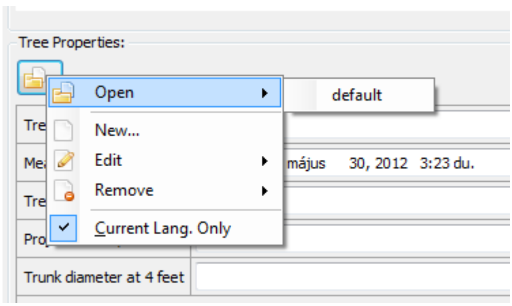
GPS and Notes

The *"GPS:"* box shows the GPS location recorded by the battery box (not supported by older devices), or the Android app. The location may also be edited by clicking the button, however this requires an internet connection.

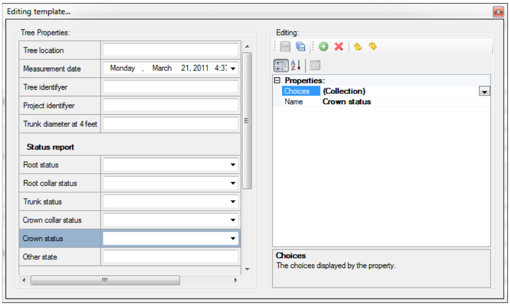
The "Notes:" box contains a field where any notes may be entered.

Tree properties

The rest of the *"Tree"* panel contains a form that can optionally be filled out, describing the state of the tree. The form shown in new projects is based on the default template, but custom templates can be created as well. The contents of the *"Tree properties"* form are also added to reports generated.



- The  button opens the tree properties menu. The menu commands allow you to open, create, modify or remove form templates (though the default, built-in template that comes with the software ca not be deleted). Each language has their own templates, but you will not be able to affect them unless you uncheck the *"Current Lang. Only"* menu item.



- Clicking *"New"* or *"Open"* opens a window where form templates are edited. The left side shows the preview of the form while the right side is used to customize rows selected on the left.
- Click the  button to add a new row. You must specify the name shown on the left side of the preview, the type of data being requested, and the position to insert to new row at.
- Use the  buttons to reorder the rows, and the  button to remove the currently selected row. Click the Save and Save As buttons () to save the changes you made. For new templates or when clicking the Save As button you also have to specify a name for the template. This is the same name that appears in the Tree Properties menu when you click *"Open"*.

Sensor Geometry

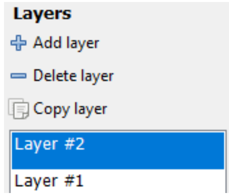
The "Sensor Geometry" panel is used to specify where exactly the sensors are placed on the tree trunk.

Layers

Layers are a core concept of the software. A single layer represents sensors placed at the same height on the trunk. The placement of the sensors is also referred to as layer geometry.

The sensors are placed one layer at a time, and after the measurements are taken they are moved to the next height. Please disconnect sensor cables when moving them, as force of removal and placement of sensors may otherwise damage the Amplifier Boxes.

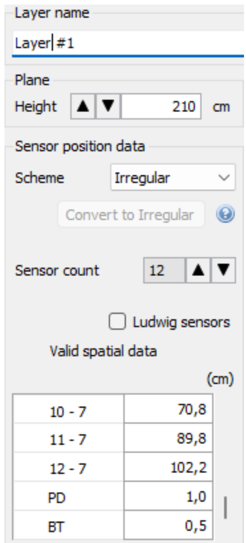
The left side of the "Sensor Geometry" panel is used to edit the list of layers in the current project, and clicking on the name of a layer will show it's data. The layer list is sorted by height, in descending order.



- **Add layer:** adds a new, empty layer to the project.
- **Delete layer:** permanently deletes the selected layer. This will delete all of the layer data, including it's geometry and measurements.
- **Copy layer:** creates a copy of the geometry of the selected layer, but not it's measurements. This is useful especially when working with irregular geometries, however care should be taken: the quality of the tomogram and therefore the evaluation depends strongly on the precision of the layer geometry.

Layer geometry

The second column of the "Sensor Geometry" panel is used to specify the sensor positions of the layer currently selected in the layer list, on the left.



- **Layer name:** an optional and purely decorative field used to edit the name of the layer shown in the layer list, on the left. Can be used to show a small amount of information in the layer list, like layer height or trunk flaws. This can help differentiate which layers is which when there are multiple layers.
- **Plane / Height:** the height of the sensor placement, measured from the ground (units may be changed in Application Settings / User interface). All layers must be placed at different heights. The height also determines the position of the layer in the list on the left side.
- **Scheme:** the general shape of the layer geometry. Use *"Circle"* and *"Ellipse"* for strictly circular or ellipsoid cross sections, and *"Irregular"* for all others. *"Rectangle"* is used for measuring beams, not tree trunks.
- **Convert to Irregular:** converts the current *"Scheme"* to *"Irregular"* (unless it already was). This can be useful if the trunk is almost circular or elliptic with only one outgrowth or dent.
- **Sensor count:** The number of sensors used for this layer.

- **Ludwig sensors:** indicates whether Ludwig sensors are being used (see: Ludwig Sensors).
- The next row indicates whether the parameters below specify a valid geometry. If there is an error then the background is red, and the text indicates the issue.
- The table contains the parameters required for the *"Scheme"* selected. There are two parameters used in all schemes:
  - **PD:** The estimated penetration depth of the nail tip from the bark surface. (The nails' lengths are usually 6 cm.) It is a critical parameter for smaller trees.
  - **BT:** Bark Thickness. This parameter is should be set carefully for small trees.
  - PD > BT, as otherwise the nail does not penetrate the bark.
- Finally the "Caliper" box is used to edit the fields in the table using a Bluetooth Caliper.

Sensor placement

The *"Sensor distances"* box (near the top of the *"Sensor Geometry"* panel) shows where sensors should be placed, based on their distance from the first sensor. (The box is empty if the geometry has an error, or for Irregular geometries.)

For Irregular geometries you place the sensors first, then measure distances between them using the Caliper. For other geometries you measure the geometry first, then place the sensors where instructed.

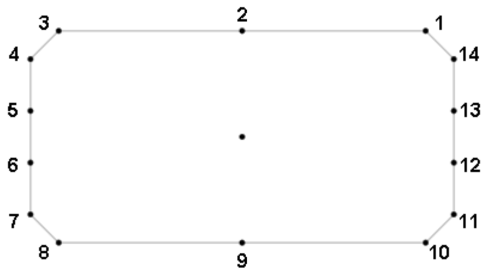
Sensors need to be placed in a counter-clockwise order when seen from above. For example the second sensor is to the left of the third, while the fourth is to the right.

- *Circle scheme:* Place the first sensor and use it as a support to hold the tape around the trunk. Measure the circumference with the tape and enter it into *"C"*.
- *Ellipse scheme:* Place the first sensor at the end of the larger diameter and use it as a support to hold the tape around the trunk. Measure the circumference with the tape and enter it into *"C"*. Measure the larger diameter (major axis) with a caliper and enter it into *"D1"*. Measure the smaller diameter (minor axis) and enter it into *"D2"*.

Rectangle scheme

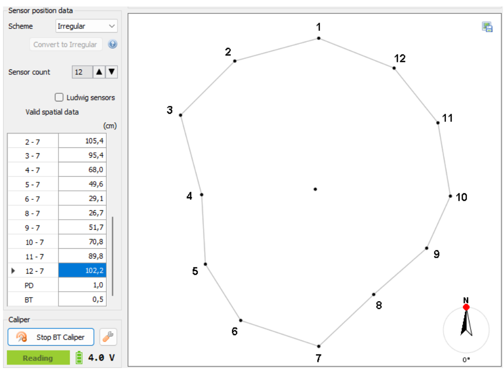
- Use if the cross section is rectangular.
- *"A"* and *"B"* are the sides of the rectangle. *"A"* is horizontal, *"B"* is vertical.
- *"ASC"* and *"BSC"* are the number of sensors on the *"A"* and *"B"* sides (A Sensor Count, B Sensor Count). 2*(ASC+BSC) must equal the total number of sensors.
- The number of sensors per side are distributed equally, with the first and last sensors at the ends of each side by default. This is not preferable, as placing sensors at the corners is difficult and each corner would have to host two sensors at the same time. *"LeftPad"* and *"RightPad"* indicate the space (padding) to use along the horizontal sides between the left/right corners and the first/last sensors on the horizontal sides. *"TopPad"* and *"BottomPad"* work similarly for the vertical sides and their sensors.
- As this scheme is commonly used on lumber material without bark, you may set *"BT"* and *"PD"* to zero. If *"PD"* is greater than zero, than you need to add *"PD"* to *"LeftPad"*, *"RightPad"*, *"TopPad"* and *"BottomPad"*.

A	30,0
B	15,0
ASC	3
BSC	4
LeftPad	2,0
RightPad	2,0
TopPad	2,0
BottomPad	2,0
PD	0,0
BT	0,0



Irregular

- Place the sensors around the trunk in counter-clockwise order.
- Make sure that the sensors are in one plane. The tape measure can be used for this.
- After placing the sensors use the caliper to measure distances between sensor



pairs. For example, distance between the first and second sensor needs to be entered in the field *“1 - 2”*.

- The Bluetooth Caliper can be used to transmit the data directly to the software. The battery needs to be at least 3.5V. The charge can be seen in the Caliper box at the bottom, after the first sensor pair is measured.

Sensor Geometry Compass

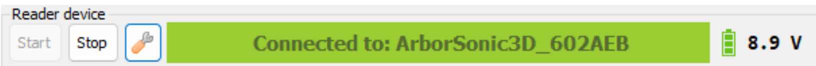
- The compass defines the compass direction of sensor 1. (by default north)
- Move the red dot to change a the direction of sensor 1.

Time Data

The *“Time Data”* panel is used to analyze measurements in progress, resolve issues during measurement and determine if further measurement is worthwhile.

On the left side the list below *“Layers”* shows the names of the layers within the current project. The currently selected layer has a blue background, and it is the layer that will receive new measurements. New layers may be added on the *“Sensor Geometry”* page (see: Sensor Geometry / Layers).

The *“Reader device”* box at the top shows the current state of the connection with the Battery Box:



- **Start:** Connects to the Battery Box. This can take a significant amount of time, though usually you should be able to connect in ~30 seconds.
- **Stop:** Stops the connection to the Battery Box.
- The orange wrench icon shows a connection setup dialog, which manages battery box connection settings and sensor redirections.

- **Sensor redirections:** When sensor redirections are active a red label between the wrench button and the status bar is shown. It shows a summary of active sensor redirections. (see: Sensor redirections).

Sensor redirections:
11→3 12→4

Figure 3: Sensor redirections notification

- The large status bar in the middle contains the current status of the connection to the Battery Box. The **Device inactive:** indicates that there is no active connection to the Battery Box.
- The right side of the box shows the battery level once it is sent.

Begin the measurement when the status bar shows a *"Connected"* status.

Device inactive
Connecting to: ArborSonic3D_602AEB
Connected to: ArborSonic3D_602AEB
Disconnecting from: ArborSonic3D_602AEB
Please turn on PC Bluetooth

Figure 4: Possible connection states

Time rows

Time rows

Remove bad rows | Remove selected rows | Remove all rows

	1 6	2 6	3 6	4 6	5 5	6 5	7 5	8 5	9 6	10 8	11 5	12 6
●	454	553	608	538	542	513	448	302	158	0	202	328
●	456	558	613	541	546	515	450	306	159	0	206	331
●	454	552	606	537	542	511	447	302	159	0	202	328

Each successful hit appears in the "Time rows" table, as a row of numbers. The columns represent the sensor number.

The numbers in the rows represent stress wave travel times in microseconds. The sensor which has been hit is represented by the number zero. The other sensors will report smaller or greater time measurements depending on how long it took for the stress wave to reach them.

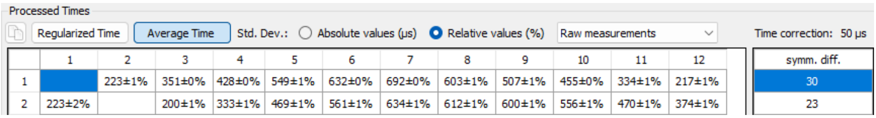
The green or red numbers in the columns indicate how many "good" hits were recorded on those sensors. Green merely indicates that the minimum number of required hits was reached, not that the measurement should be finished.

The green or red icon in the very first column indicates whether that row is a "good" hit. Red indicates that there was an issue with that hit, and hovering the mouse over it show a short description of the problem (see also: Testing and troubleshooting / Measurement errors).

The three buttons above the table are used to permanently remove time rows. Rows can not be edited, only deleted.

- **Remove bad rows:** Deletes all rows containing measurement errors. Afterward only good hits remain (with the green dot to the left).
- **Remove selected rows:** Removes the selected rows only. You can select multiple consecutive rows by clicking on the first row then holding the Shift key and clicking on the last row. You can also select multiple individual rows by holding the Control key as you click on them.
- **Remove all rows:** Removes all measurements. This can be used to remove test hits checking the equipment, before starting the real measurement.

Processed Times



	1	2	3	4	5	6	7	8	9	10	11	12	symm. diff.
1		223±1%	351±0%	428±0%	549±1%	632±0%	692±0%	603±1%	507±1%	455±0%	334±1%	217±1%	30
2	223±2%		200±1%	333±1%	469±1%	561±1%	634±1%	612±1%	600±1%	556±1%	470±1%	374±1%	23

The *"Processed Times"* box remains empty until the minimum number of good hits is received from all sensors (i.e. the column headers in the *"Time rows"* table are all green). The contents that appear afterwards are an important tool for determining the quality of the measurements taken, as well as how to improve them.

Average Time

The rows of the table represent the sensors that were hit, while the columns represent the sensors measuring the corresponding stress waves. The diagonal is therefore empty.

The non-empty cells in the table summarize the time measurements for the corresponding row and column. For example in row 4 and column 1 you will see "532 ± 47%". This indicates that whenever the 4th sensor was hit, the 1st sensor measured an average time of 532µs, with a standard deviation of 47%.

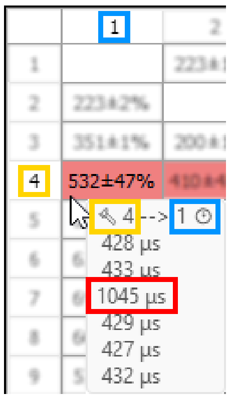


Figure 5: Hovering a single cell in the matrix shows the values for that cell

Finding bad measurements from average times

Time rows with measurement errors (red icon to the left) are ignored by the tomogram and biomechanical evaluation so they can be left alone. Some users find them distracting, in which case they can be easily removed using the *“Remove bad rows”* button.

Some time rows - while technically without error - can show anomalous time measurements. While the software tries to ignore these, it is best practice to manually remove them and ensure they do not affect the tomogram and the biomechanical evaluation.

In the *“Processed times”* table, some cells are marked with red backgrounds. These cells have a standard deviation that seems unusually high (5% by default, though this can be changed using the *“Rel. Time Error Threshold (%)”* field in the project options; see: Tree / Project options). Each of these cells should be individually reviewed. Note that cells below 10% deviation might be normal.

When the mouse hovers over a cell it displays the time measurements between the sensor hit (row header) and the sensor measuring (column header). If there is just one or two measurements that are causing the issue, they should be easy to identify. Once found, the time row with that exact measurement should be deleted.

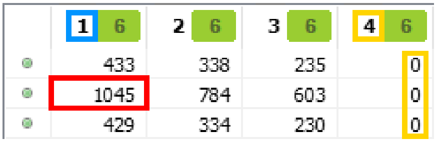


Figure 6: An example for outlier time measurement in the time rows. Here sensor 4 was hit.

It is good practice to always hit a couple more times after the minimum amount of good hits is reached for a sensor. This way if you later have to delete one or two measurements, you will still have enough remaining. This also helps identifying which time measurements are anomalous. For example consider the following 3 measurements between 2 sensors: 400, 450, 900. Here 900 is clearly wrong, however we don’t really know 400 or 450 is closer to the truth. If you keep measuring you might see a pattern form: 400, 450, 900, 440, 460, 445. In this case good measurements seem to be around 440µs to 460µs, and the 400µs and 900µs measurements are wrong. This shows the benefits of having more hits: you will be able to identify correct measurements.

The recommended minimum number of good hits per sensor is 5, but a couple more might always come in useful later.

Finding bad measurements from symmetric differences

The right side of the *“Processed Times”* box contains the list of what ArborSonic3D calls “symmetric differences”. Consider two sensors: ‘A’ and ‘B’. When you hit ‘A’ you measure from ‘B’, but eventually you will hit ‘B’ and measure from ‘A’. You would expect that measurements from both ‘A’ and ‘B’ to be mostly equal, since the distance between the sensors and the material between them did not change. However sometimes you will see a large difference in one direction compared to the other. In this case the symmetrical difference for the corresponding sensors will be high. There a couple issues that might cause this:

- bad acoustic coupling: when the sensor is not firmly in the material
- sensor in low velocity area: such as decay
- noise from an external source: while measuring with one of the sensors there was some kind of noise, for example a tape measure that was not removed from the trunk

The symmetric difference for a sensor ‘N’ is derived from the differences in the times measured in different directions between ‘N’ and any other sensor. For example for sensor 3 it would be based on the difference in measured times between (3→1 and 1→3), (3→2 and 2→3), ... etc.

Only a basic guideline can be provided on which values are wrong as they may depend on the geometry, wood material and other factors.

The following list generally applies as a basic guidelines regarding the symmetrical differences:

- In an intact tree with ideal conditions and good acoustic coupling it possible to get the symmetrical differences under 20.
- Up to 100 us: with significant decay it is possible for symmetrical differences to reach approximately 100 us.
- Above 300 us: Serious acoustic coupling issue, such as that the nail is not firmly in the material or it is placed into a decay.
- Above 500 us: If consistent, very likely an issue with the sensor or the amplification.

Note that a worse condition and larger samples always result in higher symmetrical differences.

Miscellaneous items in Processed Times

There are a few last items in the “Processed Times” box. These are rarely needed by most users and can be ignored:

- the copy button : copies the content of the table to the clipboard
- **Regularized Time:** single time measurements corrected for radial-tangential differences and travel time in sensors (time correction)

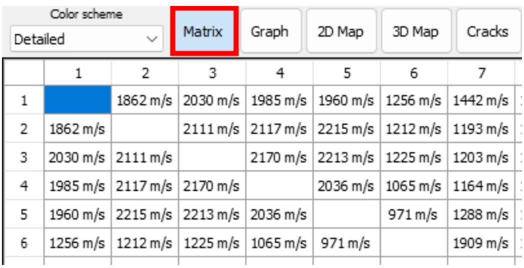
- **Average Time:** the default view discussed in the chapters above
- **Absolute values (µs):** show standard deviation in microseconds
- **Relative values (%):** show standard deviation in percentages
- drop-down list: When *"Raw measurements"* is selected, the table is calculated from all time rows. *"Auto-filtered measurements"* attempts to remove bad time rows before calculating the table similar to the chapter Finding bad measurements from average times. *"Auto-filtered measurements"* shows what will be used to calculate the tomogram, but is less useful for detecting bad time rows.
- **Time correction:** the time it took for the sound wave to travel in the sensor. The software subtracts this from the measurements to produce the 'Regularized Time' matrix.

Tomograms

The "Tomograms" panel is used to view visual representations of estimated stress wave velocities. Stress waves traveling through healthy material have generally higher velocity than those traveling through decayed material. It is very important to know that tomograms do not show the health of the measured section of the trunk, but simply indicate how stress wave velocity in the cross section. This often correlates with the health, but it is an important fact to keep in mind. Ring shakes and internal barks are both capable of lowering the measured velocities.

The layer list is seen on the left side. The *"Multilayer model"* at the top shows all tomograms when there are multiple layers.

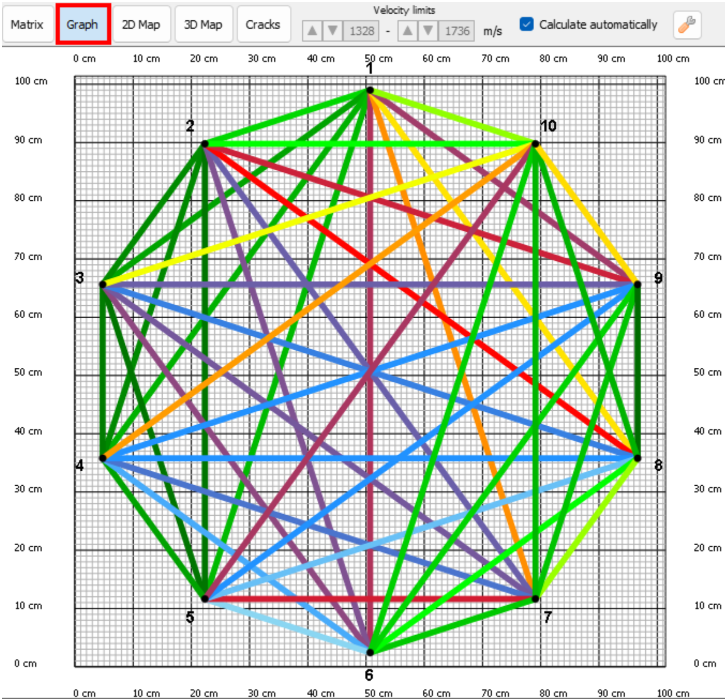
Matrix view



	1	2	3	4	5	6	7
1		1862 m/s	2030 m/s	1985 m/s	1960 m/s	1256 m/s	1442 m/s
2	1862 m/s		2111 m/s	2117 m/s	2215 m/s	1212 m/s	1193 m/s
3	2030 m/s	2111 m/s		2170 m/s	2213 m/s	1225 m/s	1203 m/s
4	1985 m/s	2117 m/s	2170 m/s		2036 m/s	1065 m/s	1164 m/s
5	1960 m/s	2215 m/s	2213 m/s	2036 m/s		971 m/s	1288 m/s
6	1256 m/s	1212 m/s	1225 m/s	1065 m/s	971 m/s		1909 m/s

The *"Matrix"* button shows a symmetric matrix of the measured stress wave velocities between sensors. Particularly low velocities are of interest, as they may indicate that there is decay or a hollow between the sensors.

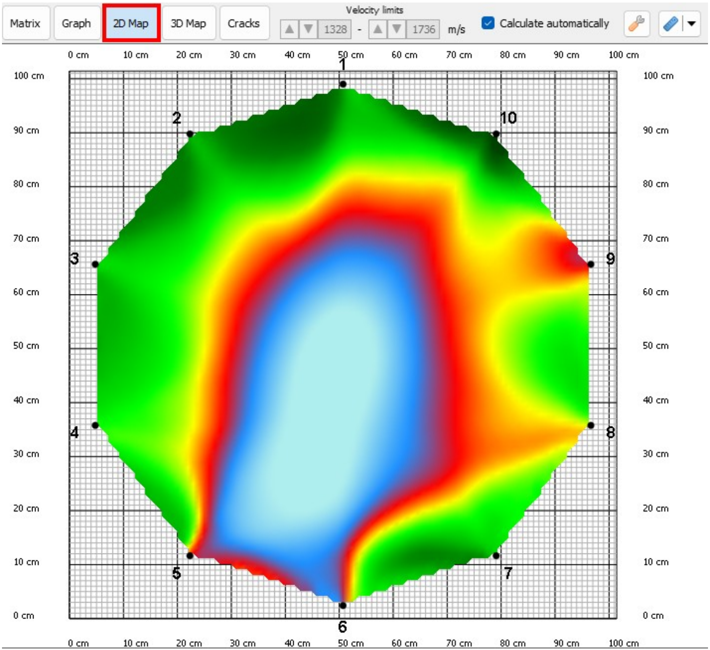
Graph view



The *"Graph"* button shows a graph of the stress wave velocities shown in the *"Matrix"* view. You can view the measured velocity between sensor pairs by hovering the mouse over the lines.

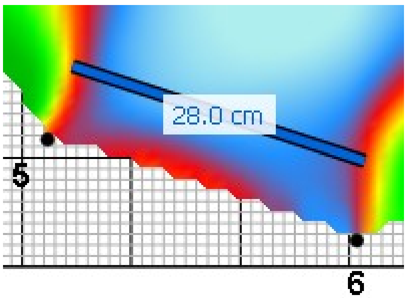
Of particular interest is when all or most lines from a sensor are blue or red, as that may indicate decay or a hollow at the sensor.

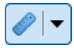
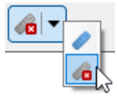
2D Map



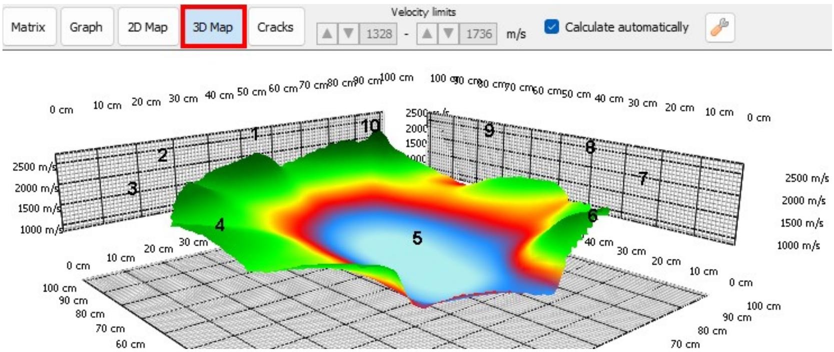
The *"2D Map"* button shows a 2-dimensional map of the estimated stress wave velocities not just between sensors but throughout the cross section. Hovering the mouse over any point in the layer shows the coordinates and the velocity.

In this view you can measure lengths using "rulers". Rulers are blue line segments that indicate their length. The last button in the toolbar at the top is used to add/move or remove rulers.



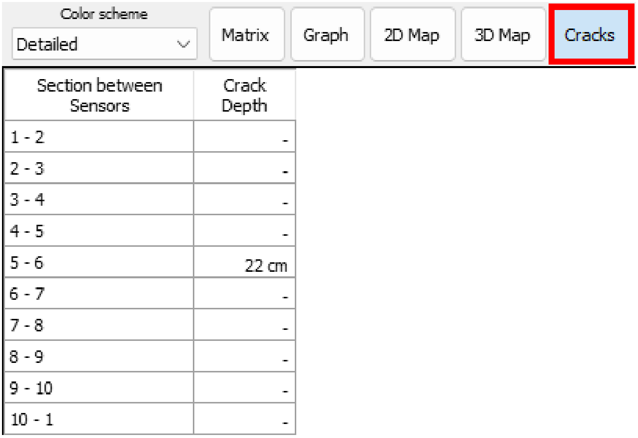
- When the button has a gray background rulers can be neither added, moved or removed. 
- Clicking on the blue icon turns the button background to blue, and causes mouse clicks on empty areas to place an endpoint of a ruler. Clicking and dragging the endpoint of an existing ruler moves will move it. 
- Clicking on the gray icon with the red 'X' in the corner turns the button background to blue and causes mouse clicks to remove existing rulers. The icon on the button can be changed by clicking on the downwards arrow on the right side. 
- To finish using rulers and stop mouse clicks from affecting them press the icon of the button to turn it's background gray.

3D Map



The *"3D Map"* button visualizes the content of the "2D Map" as a 3D surface. This can emphasize the relative difference in velocities. The view can be rotated by holding the left mouse button and dragging.

Cracks view



Section between Sensors	Crack Depth
1 - 2	-
2 - 3	-
3 - 4	-
4 - 5	-
5 - 6	22 cm
6 - 7	-
7 - 8	-
8 - 9	-
9 - 10	-
10 - 1	-

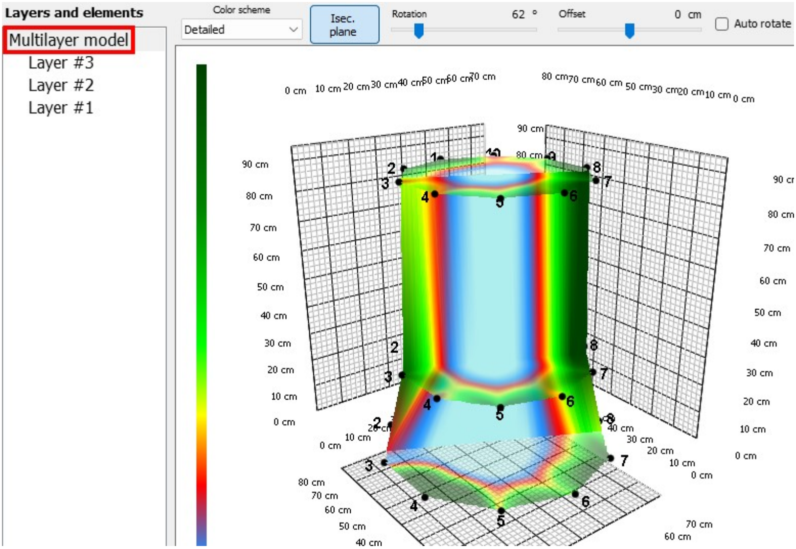
The “Cracks” button shows the estimated depth of cracks starting from the surface. However this tool does not detect internal cracks.

Tuning tomograms

The images in the “Graph”, “2D Map” and “3D Map” views can be further refined manually.

- **Color scheme:** can select an alternative color palette to visualize velocities. The recommended color scheme is *“Detailed”*. The legend of colors is displayed on the left side.
- **Velocity limits:** this velocity range determines the colors assigned to velocities.
- **Calculate automatically:** unchecking this box allows adjusting the colors of tomograms by editing the *“Velocity limits”*. Automatic calculation is the recommended setting.
- **Minimal Line Velocity:** this option clamps the speeds calculated by the tomogram to a specified minimum. It may be set in the *“Tomogram options”* window opened by the wrench  button. It can be used to fix certain tomogram artifacts caused by extremely low velocities.

Multilayer model



If there are at least 2 layers in the project than a 3D representation of all layers at once can be shown. The view can be rotated by holding the left mouse button and dragging. Please note that the 2D maps used each have their own velocity limits, and therefore the same color on 2 different layers may refer to different velocities. This is because it is not unusual that average velocities in even healthy wood material may change based on height, for example between ground level and chest height.

A vertical plane intersecting the layers may be enabled by clicking the *"Isec. plane"* button. The colors of the plane interpolate between the colors at the points it intersects the layer maps. This is an interpolation between the layers at different heights. The intersection place may be positioned manually using the *"Rotation"* and *"Offset"* sliders, or it's rotation can be changed to automatically face the viewer by checking *"Auto rotate to face you"*.

The 2D maps of the layers are positioned over one another, with the distance between them being proportional to the layer height specified in *"Sensor Geometry"*. This can be inconvenient when some layers are close to each other, in which case by checking "Equidistant display" layers will be spaced equally (the effect is visual only, the layer height is not changed).

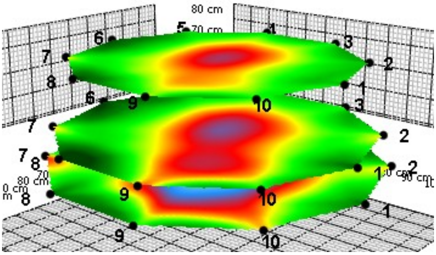


Figure 7: Equidistant off

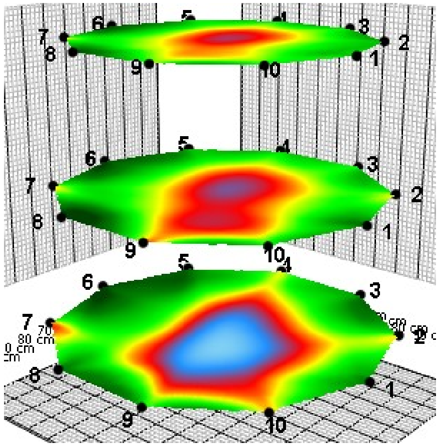
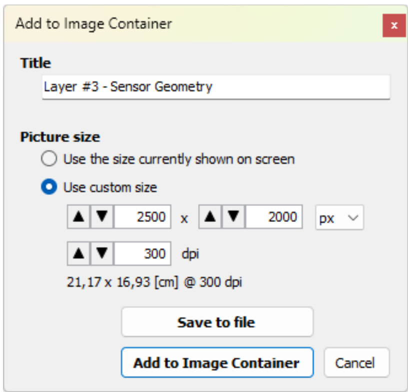


Figure 8: Equidistant on

Exporting images

One of the common tasks after measurement is to take a tomogram image from the software and add it to a digital or printed report. Images can be saved by clicking the  button in the top-right corner of the *"Sensor Geometry"* and *"Tomograms"* panels.



You need to decide if you wish to add the image to the *"Image Container"*, or a separate image file. If you generate reports from the ArborSonic3D software then it's easiest to just add the image to the image container. However if you wish to manually add images to another software (e.g. Excel, Photoshop, email, ... etc.) then you need to save a separate image file, as other software can not read the ArborSonic3D file format.

The name entered into the *"Title"* field is used either in the file name if saving to a separate image file, or the name shown in the "Image Container".

The next task is to specify the size of the image to be saved, under *"Picture size"*. If you merely wish to view the image later on the computer, than selecting *"Use the* *size currently shown on screen”* will preserve the currently visible size on your monitor (the size may change if viewed on another monitor). However if you intend to print the image later than that commonly results in blurry or small images on paper, so you need to select *“Use custom size”*. Specify the image size in either pixels or centimeters/inches (based on the current measurement system used). It is very important to specify the DPI (dots per inch) that will be used when printing. 300 dpi is commonly used for office documents.

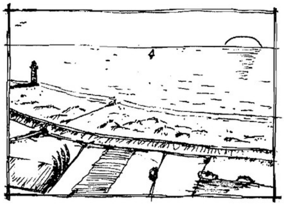
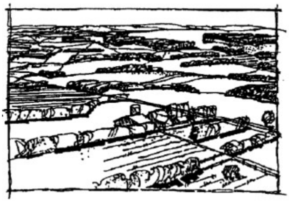
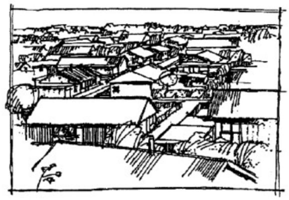
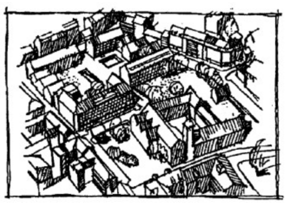
Biomechanics

- The Biomechanics page allows you to evaluate the Safety Factor of the tree trunk using the obtained cross-sectional tomograms at the specified wind load.
- The process gives an estimate for the trunk safety. Please note that only the tomograms at the measurement Layers are used, therefore the software is not aware of any parts outside the measured region.
- The program offers two different models for calculating wind load:
    - The “Uniform” wind load model uses a relatively simple model to estimate the load, force and torque caused by wind. This model usually calculates higher wind load and lower Safety Factor for trees below 20 m.
    - The “EN1991” wind load calculations are based on the EUROPEAN STANDARD EN 1991-1-4 (also known as EUROCODE). The standard calculates wind loads on buildings, which was adapted for trees.

Wind

- For the uniform wind load calculations, the expected highest wind velocities are needed.
    - Wind velocity must be set to the highest expected wind gust speed, which is usually 33m/s or 75 mph but can be even higher like 45 m/s in coasts, mountain areas and so on.
    - Try to estimate what wind velocity will actually reach the tree. Consider if the tree stands windward or leeward.
- Using EN1991 wind load evaluations the terrain category should be chosen first.
    - Basic wind velocity is a region dependent value defined by the national annex for each country. Consult your national annex or a 3rd party service like dlubal.com to get the correct values for your location (see: https://www.dlubal.com/en/solutions/online-services/geo-zone-tool)
- Dry air temp. is the temperature of the air in dry conditions. This value effects the calculated wind load.

EN1991 Terrain Categories

0	Sea or coastal area exposed to the open sea	
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	

Crown

- There are multiple ways to describe the tree crown to the software. “Manual” is only available for UNIFORM calculations, “Calculator” and “Drawn” is available for both UNIFORM and EN1991.
- For “Manual” simply enter the parameters of the crown.
- “Calculator” is similar:
    - Click the  icon. This dialog window requires the width, height of the crown and a shape factor. The calculated area is simply: width * height * factor. Predefined factors can be selected by choosing the assumed crown shape. (Using a custom factor is also possible for the UNIFORM model.)
    - Center of height should be given in UNIFORM model (when using EN1991 this is automatically calculated from the shape data). This height is the height of the crown’s center, not the center of the whole tree.
    - Bottom height is the height of the bottom of the crown, where the crown starts.
- The “Drawn” option uses a photo with the tree as a reference. The photo should include the whole tree. It is recommended to take the photo from a distance of at least the height of the tree to avoid distortions. After opening a photo, it is needed to mark the crown area, a reference height and the lean of the trunk.
    - Click the  button in the Image Editor tab under Image Container section and load a photo of the tree. If the tree has substantial inclination, then it is recommended to take the photo from a direction where this inclination can be seen. After loading and selecting the photo you can use the  button to collapse the image container to gain more space on the screen.

    - Use the  button to mark the shape of the **crown**. **Please mark the area of the crown only.** (The area of the trunk will be calculated from the layer diameters and heights by the software.) Click once for each point. Closing the curve and finishing marking by clicking OK.

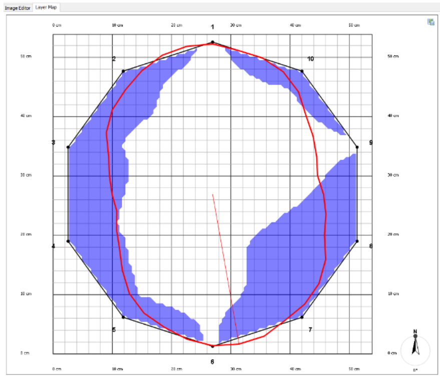
- The reference length can be marked with the  button. This is the length of a person or some reference object fully visible on the image at the depth of the tree. Two clicks place a blue line with a “???” text on the line. Click the text or OK to enter the physical length of the object. If the height of the tree itself is known, it is better to use it as reference.
- The  button can be used to measure the degree of tilt (lean) of the trunk. It is a yellow line consisting of two segments: one for the trunk, the other for the ground level. You need to place three points. The first point must be placed **at the bottom of the trunk**, and is marked by a square. The endpoints are marked by a circle: one should point in the direction of the trunk and the other should show the horizontal direction. The points can be moved using the mouse. If it is not possible to indicate the actual tilt from the photo you can enter it manually by unchecking “Draw tilt angle” on the left side of the window, in the “Trunk” group. Click “OK” once done to finish placement.

- The Safety Factor can not be estimated if one of the lines is not drawn (Crown area, reference height and direction of trunk).
- The buttons in the right-bottom corner can be used to rotate the image, zoom in and out and change the color palette (in case one of the lines is difficult to see).

Trunk

- “Degree of lean” is the amount that the tree tilts. It is either drawn on the photo or manually entered. 90° represents a completely vertical trunk.
- “Direction of lean” always needs to be provided manually, even for “Drawn” crown models. Choose one of the options (North, North East, East,...) or enter it manually by selecting “Manual”. 0° means North, 90° means East.
- On the top of the right area, next to “Image Editor”, there is the “Layer map” tab. Here a simplified map of the selected layer can be found.

- The areas where the sound velocity is under the average of minimum and maximum values are white (see: Velocity limits in Tomograms). This is damaged, decayed wood which lost its load bearing capacity.
- Blue color indicates to wood capable to hold the loads.
- The program calculates mechanical stresses for all wind directions (every 5°) This is shown as a red contour. The red line from the center to the edge shows the highest stress (weakest direction). The Safety Factor is the estimated for this direction.
- This how mechanical stress changes with wind directions.
- The "Layer map" only uses the selected layer in it's calculations.



"Tree", "Layers" and "Details of the selected layer"

- Wind load is the force acting on the crown, calculated by the software.
- Center height is a simplification, Uniform model uses this height as the attack height for the wind's force to calculate the load. Similar height is calculated back from the wind load in EN1991 as well.
- Drag factor is the drag coefficient of the crown, taken from the tree species database.
- Yield strength is the yield strength of the trunk wood, also taken from the species database.
- The table lists all the layers.
    - the first column is the name of the layer
    - the second column is the layer height as provided on the Geometry page
    - the third column is the decayed area within the cross-section at the layer height. It is the percentage of the decayed region of the selected layer compared to the total layer area
    - the Safety Factor for the specified layer is in the fourth column
    - the fifth column is the simplified Risk Rating.

Safety Factor	below 50%	50% - 100%	100% - 150%	above 150%
Risk Rating	**Extreme Risk**	**High Risk**	**Moderate Risk**	**Low Risk**

- "Avg. T/R" is the average ratio of the intact wall thickness to the trunk radius. Some scholars recommend that the trunk is safe if this value is above 0.3. However, the Safety Factor calculations do not use this parameter. The exact formula is: $AvgT/R = 1 - \sqrt{DecayedAreaRatio}$.
- "Tree weight above layer" is the estimated total weight of tree that is above the selected layer.
- "M" is the torque resulting from the wind.
- "Max stress" is the maximal stress resulting from the torque and mass of the tree, taking into consideration the tomogram.
- "Safety factor" is the ratio of the wood strength from the species database as shown as YieldStrength and this computed maximal stress. The formula is SF=YieldStress/MaxStress. The rationale behind this approach is that given all the parameters above the software tries to estimate the stress in the wood and if this exceeds the maximum limit the material can resist, then the trunk would break.
- In UNIFORM wind model Safety Factor is calculated for a tree standing alone and exposed to the total effect of wind. Trees standing next to each other, close to buildings, in parks and so on can be protected against wind and the calculated Safety Factor may therefore be lower than real one. While if the tree stands in a wind tunnel the calculated safety factor may be higher than the real one.
- EN1991 model considers the surroundings as well while calculating the Safety Factor. Experience shows that the Safety Factor calculated by UNIFORM model is usually similar to the one calculated for the "Village" terrain category.
- The model expects intact outer walls (tube shape) for the trunk. The resulting safety factor does not apply when dealing with a split or open trunk.
- The software takes the minimum of all the safety factors and displays it at the bottom. A tree might be considered safe if Safety Factor is above 150%, using an additional 50% for overestimation. In this case the text appears in green. Otherwise, if the value is between 100% and 150%, the tree is in the gray zone and the text is shown as light yellow. If the value of below 100%, the tree might be considered unsafe and the text is shown as red. The weakest layer can be seen in the list where the corresponding safety factor is the lowest.

- WARNING! Special care needs to be taken at all times. Although the software tries to over-estimate the risks, the calculation of the safety factor model has simplifications and an error range. In case of incorrect use, the tomogram and the entered data might be erroneous as well. You are solely responsible for ensuring that the System is appropriate for the use you put it to, and you understand that is only one part of what is needed to assess the health of trees and similar green assets. Note that the System is just one tool to be used, along with your experience and training in assessing these living organisms, that the System cannot be relied upon as the sole source of evaluations, and that all hardware and software is subject to failure or misuse.

Image Container

- The image container panel shows the images added to the project. The content is the same as what is seen on the Biomechanics panel. Tomogram images exported by clicking and then “Add to Image Container” appears here. These images may optionally be added to reports generated.
- You can open an external image with the button and export an image from this container to an external file with the button. The button can be used to remove an image from the project.
- Use the , buttons (or the slider between them) to change what size the images are shown at. This does not change however the actual size of the images, merely their preview.
- Clicking the title of an image or using the button allows you to change it.

Generating reports

- The built-in report generator creates simple reports from the project data.
- Go to the Report page, select the list of images you wish to include in the report and click the “Generate report” button on the bottom right.
- The report is created in the Microsoft Office (.docx) format, and can be edited further afterwards.

ArborSonic 3D Android Application

The Android app for ArborSonic 3D can be installed for free from the Google Play Store (see: https://play.google.com/store/apps/details?id=com.fakopp.arborsonic3d)

The Android app has a reduced feature set compared to the desktop application. It's main features are:

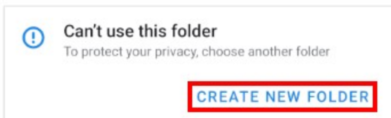
- selecting tree species
- specifying sensor geometry
- taking measurements
- viewing a rough preview of the 2D tomogram (of the PC software)
- adding photos to the current project
- using the Android GPS module to record the current location

You mainly use the Android app to make taking measurements easier, however to evaluate them you need to open the projects saved into the PC software.

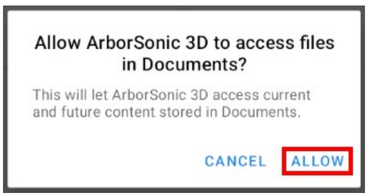
Project directory

When the Android app starts for the first time, it requires the user to specify a folder to keep it's project files in.

It is recommended to create a folder within "Documents" or "Download", as these are usually visible when connected to the PC using a USB cable and when file sharing (also called "File transfer" or "MTP") is enabled in Android. This is should make it possible to copy project files to the computer directly from this folder.



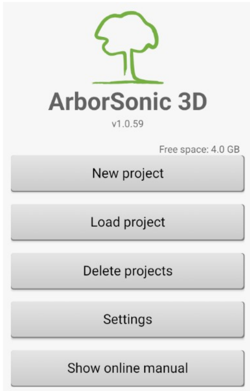
Some folders do not allow the app to place project files within them directly. However in these cases you should be able to create a new folder within, and use that instead.



Once a folder is created, tap the *"Use this folder"* button, and then *"Allow"*, to grant access to the folder.

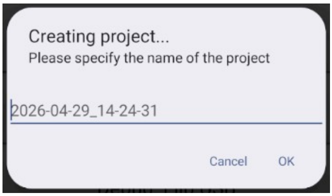
This procedure must be done only once, though the directory may be changed any time using the *"Settings"* menu. It is also possible to reset app permissions in Android, which may result in having to specify this folder again when the app next starts. Newer Android devices also automatically revoke permissions for apps that have not been used for a long time

Main menu



The main menu allows managing the project files, accessing the app settings and opening the manual in the browser.

- **Free space:** Indicates the free space available on the phone. It is good practice to keep an eye on it, as low disk space may slow down android, and extremely low disk space may cause issues with saving projects. It is recommended to keep at least 1-2GB free (preferably 10-15% of the total storage capacity). The text will be red if the free space available is very low. In this case you should immediately delete some projects, images, videos, apps, downloads, ... etc. to free up space.
- **New project:** Shows a dialog requesting the name of the project to be created. The default name contains the current date and time only, but you may type in another name. Characters not valid in either Android or Windows file names (\, /, :, ?, ...) will be automatically removed.

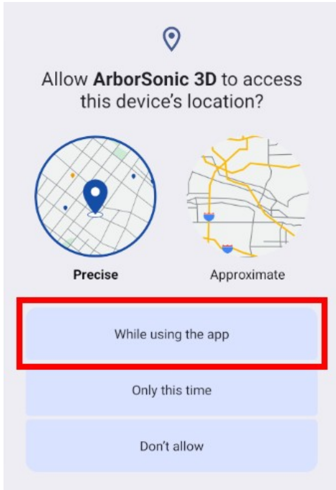


- **Load project:** Shows a list of available projects. Tap one to open it.
- **Delete projects:** Shows a list of available projects. Check the box next to the names of the ones you wish to delete. This operation is irreversible, you will lose these project files and all data within them.
- **Settings:** Change application settings, most importantly the language in use.
- **Show online manual:** Open the latest online manual. Does not work if there is no internet connection.

Project view

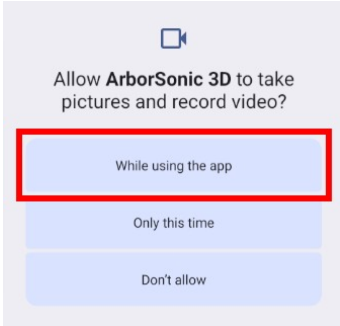
The project view is shown when a new project is created, or an existing project is opened. At the top the file name and the selected tree species is shown, as well as optionally the last known GPS location (if it was specified using the *"GPS"* button, or provided during measurement by the battery box).

- **Select Tree species:** Shows a dialog containing a short list of recently used tree species (if there are any). You can either select a recent species or cancel the dialog and enter the Latin or common name of the species. A list of matching species is displayed below as you type.



- **GPS:** Attempts to record the current location of the Android device using the integrated GPS module (if there is one). You may have to grant permission for the app to access the GPS location. Determining the current location may take some time, even up to a couple minutes. Please note that obstructions and electromagnetic interference may prevent a GPS lock. Tap the green "OK" button, once the location is available.
- **Add layer:** Adds a new, empty layer to the current project using the specified name, then opens it.
- **Copy layer:** Creates a copy of the sensor geometry of an existing layer, and then opens it (measurements are not copied). Please remember to update the layer height afterwards.
- **Select layer:** Opens an existing layer of the project, if there are any.
- **View project images:** Shows the images added to the project. The *"Prev."* and *"Next"* buttons change the image shown, while the *"Delete"* button permanently removes the displayed image from the current project. The text below the image is the file name of the image, it may contain the date and time it was taken, or it may simply be a random string of characters.
  Images added to the project can be used during biomechanical evaluation in the PC software.

- **Take a photo:** Uses the camera app to take a photo and add it to the project. You may need to grant permission to access the camera. Depending on the camera app, you may also need to select “OK” or “✓“ after taking a photo.
  The photo should include the whole tree. It is recommended to take the photo from a distance of at least the height of the tree to avoid perspective distortion.



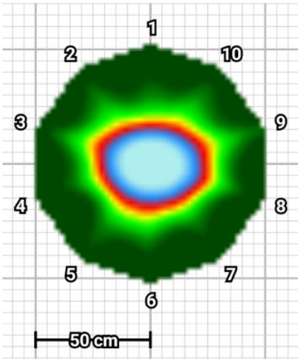
- **Add phone image:** Adds an image file to the project, using the gallery app. This may be useful if you wish to add an image previously taken with a camera app.
- **Edit notes:** Optionally enter notes associated with this project. They may be viewed later in the PC application (see: Tree / GPS and Notes)
- **Share:** Share the current project file with any app installed that accepts files. You can use this to create and send to yourself an email with a file attachment using the Gmail app, and then later open it up on the PC. Other apps accepting files/attachments may work as well (e.g. some communication or file management apps).

Layer view

The layer view allows reviewing or modifying the layer geometry and measurements.

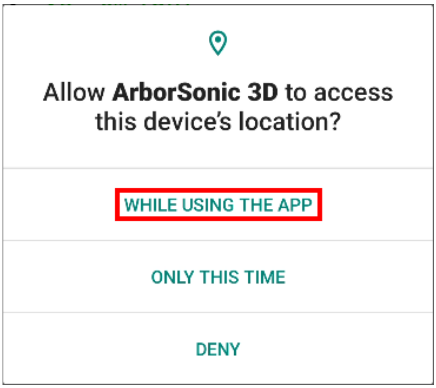
- The layer name is shown at the top, and may be edited by tapping on it.
- **Edit geometry:** modifies the sensory geometry of the layer. See: Entering Geometry.
- **View geometry:** shows a 2D view of the cross section of the trunk at the layer height.
- **Sensor distances:** shows the distance of each sensor compared to the first sensor. This helps position the sensors of Circle and Ellipse geometries at the correct position, with the help of a tape measure.

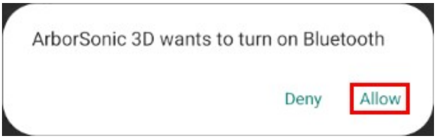
- **Read from device:** establishes a Bluetooth connection to the battery box to take measurements. See: Taking (time) measurements.
- **View tomogram:** calculates a 2D tomogram from the measurements taken. This tomogram has a reduced resolution compared to the PC software, but it is useful for a superficial evaluation of the layer.
- **Delete layer:** deletes the current layer, including the sensor geometry and all measurements. This action is not reversible.

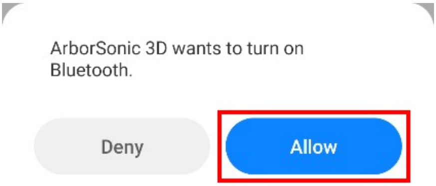


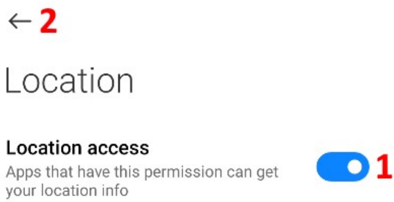
Bluetooth permissions

You may need to grant the Bluetooth and Location permissions to the app when trying to take measurements, or when trying to use the Bluetooth Caliper. It is important to allow both permissions, as depending on the device the app may not work otherwise. (The Location permission is required by Android, as scanning for Bluetooth devices may reveal your location to other nearby Bluetooth devices.) Due to the wide range of Android devices available the dialogs requesting the permissions can look slightly different. Here are some of the common ones:





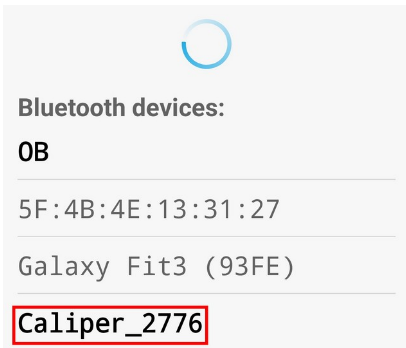




Bluetooth device search

When taking measurements using the battery box or the caliper, the first step is to select the Bluetooth device to connect to.

- Turn on the battery box or press the yellow button on the arm of the Caliper to turn it on. The Bluetooth device search only finds the devices when they are turned on. Note that the Caliper automatically turns off after a while.
- If you see nothing but the blue spinning circle and the *"Bluetooth devices:"* label, then your Android device is unable to detect other Bluetooth devices close to you. This may be because they are turned off, or an obstacle blocks their wireless signal.
- New Bluetooth devices found always appear at the bottom of the list. The list can be scrolled vertically.
- A bold font indicates that the device is active, while a slimmer gray font indicates that the device has not communicated in a while (possibly turned off or left detection range).
- The name of a Bluetooth device can not always be determined, in which case their Bluetooth address is shown instead (pairs of numbers and letters separated by colons). This usually happens when a device appears at the



edge of the detection range, and then shortly afterwards disappears. If the unknown device remains within range of your Android device, it's name should eventually appear.

- Tap a device to try connecting to it. Only active devices (bold font) with a valid name (containing "Caliper" or "ArborSonic3D") can be connected to. (You can not connect to "Caliper" devices when taking measurements, and vica versa).
- During connection you will see a *"Connecting:"* label. If the connection attempt fails, the Bluetooth device search begins anew.

Entering Geometry

Setting the sensor geometry is very similar to the PC software. The largest difference is in the use of the Bluetooth Caliper. You may wish to review the detailed instructions in the Error: Reference source not found and Error: Reference source not found chapters.

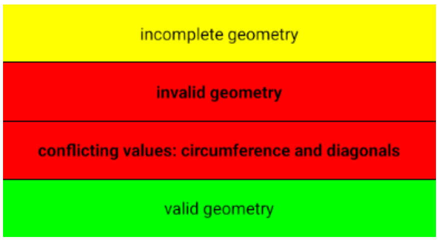


Figure 9: Geometry states

- The top of the screen shows a status bar. This indicates whether the current geometry is usable, and if not then it may indicate the issue.
- **Height:** the layer height in centimeters. Each layer needs to be at a different height (review after copying a layer on the Project view)
- **Number of sensors:** the number of sensors in use at the current layer. Needs to be an even number.
- **Sensor layout:** indicates the current sensory geometry shape. Tap to change. Rectangle layouts are only supported on the PC.
- **Start Caliper:** tapping on this button starts to connect to the Bluetooth Caliper. You may need grant Bluetooth and Location permissions (see: Bluetooth permissions), and then search for the Bluetooth Caliper (see: Bluetooth device search). This button is hidden for the *"Circle"* sensor layout, as the Caliper can not be used for it.
- The rest of the view contains the parameters of the selected sensor layout. You may need to scroll the screen up or down to bring fields into view.

You must resolve issues in the current geometry until you see the green *"valid geometry"* bar at the top of the screen.

Using the Caliper

After granting any missing permissions (see: Bluetooth permissions), and then searching for and connecting to the Bluetooth Caliper (see: Bluetooth device search), the caliper view is shown. The screen has three parts: the status of the connection to the device, the next sensor pair to measure the distance of, and the list of measurements taken.

Caliper connection status

- The *"STOP"* button ends the current connection. This can be used to abort measuring the layer geometry.
- The name if the device that is connected is above the status bar.
- The background color of the status bar indicates the state of the connection. Green indicates the connection is healthy, yellow indicates the connection is either being set up or broken down, while red indicates an error.
- Beneath the status bar the state of the battery should be indicated (except for some older devices), after the first measurement is taken.

Caliper measurement progress

- The "⇑" and "⇓" buttons select the previous or next sensor pair from the list below. They indicate the next distance to be measured. You only need to use them to repeat a previous measurement.
- The list of distances is scrollable, you may need to scroll up or down to see previous distances measured.
- Press the yellow button on the arm of the Caliper device to take a measurement. If the measurement is detected the screen indicates the next sensor pair and you are notified of the next sensor pair to be measured.
- Once the final distance is measured the view automatically closes and returns to the geometry view. Here you can review the measurements taken; errors will be highlighted.

Taking (time) measurements

While the physical steps of taking measurements remain unchanged to what is described in the Software / Time Data chapter, the Android user interface is starkly different. There are two ways of viewing the current progress: the *“summary”* and *“times”* tables.

The connection status is shown similarly to the Caliper (see: Caliper connection status). One optional addition is a list of sensor redirections. For details about setting, clearing or interpreting sensor redirections see: Configuring sensor redirections.

Sensor redirections
11→3 12→4

Measurement summary table

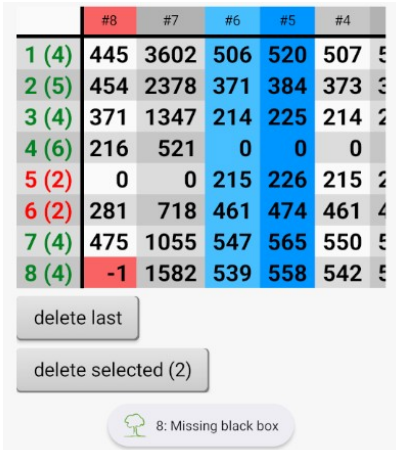
The summary table is the older visual representation of measurements taken. It loosely reflects the contents of the time matrix at the bottom of the “Time Data“ tab in the PC software (*Time Data / Processed Times / Average Time + Relative values (%)*): rows in the PC software correspond to rows in the summary table. There are 4 columns in total:

- The first column shows the sensor numbers (based on the sensor count of the current geometry).
- **#:** The number of hits on the specified sensor. Zero indicates that the sensor has yet to be hit. Red font color indicates that the minimum number of hits (3) has yet to be reached, otherwise the number is green.
- **Deviation:** The maximum deviation from the row of the current sensor within the time matrix of the PC software.
    - Consider all time measurements between two sensors, where only one of them is hit. Let’s say measurements between sensor 3 and 6, where sensor 3 is the one being hit. You would usually not expect a large deviation in these time measurements, however measurement errors (decayed wood material, loose sensors, bad hits, ... etc.) may can increase the deviation calculated.
    - The numbers in this column indicate the maximum deviation measured from the current sensor (let’s say sensor 3), to all other sensors (so the maximum of deviations between sensor 3 and 1, 3 and 2, and so on).
    - A high value indicates that there is a sensor pair where the deviation was high, but there is no further information about which sensors is involved. It is recommended to perform a couple extra hits on such sensors, though the “High” warning will usually remain. In that case the issue should be resolved by identifying and deleting bad time rows in either the *“times”* table, or the PC software.

- **Symm. diff.:** This column contains symmetric differences, which are the same as those seen in the PC software (see: Software / Time Data). The use of this column is similar to the *"Deviation"* column: if the number is high (e.g. min. ~100µs) then perform a couple extra hits on the sensor and remove bad time rows afterwards. This column is not shown when some sensors have yet to receive the minimum amount of hits (3).

Measurement times table

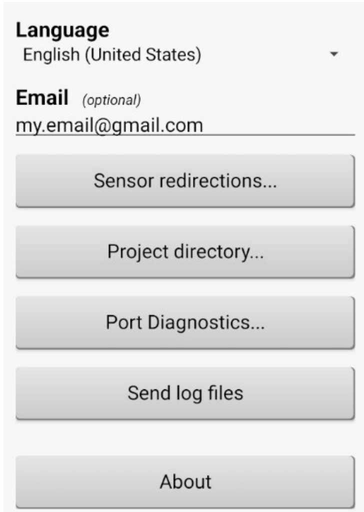
The *"times"* is almost the same as the time rows seen in the PC software (see: Software / Time Data). The main difference is that instead of rows, measurements are represented by columns (this is because a majority of users use a phone to run the app, and this way they don't have to rotate the screen to see more details).



- The first column shows the sensor numbers, and next to them the number of "good" hits detected for them in the brackets. The text is green if the minimum number of good hits was reached (3), and red otherwise.
- A hit is considered "good" if no error was detected from them. Measurement errors are indicated with red backgrounds in their columns. Tap the column to show a short message describing the issue at the bottom of the screen.
- The first row indicates the order measurements were received in. For example *"#4"* indicates that the column was the fourth measurement. This number is also shown at the start of measurement error messages. The background is red, if there is a measurement error.
- The measurements will eventually run out of horizontal screen space. New measurements are always inserted to the left and will be automatically scrolled to. Older measurements can be scrolled to manually. When the sensors do not fit vertically into the screen, then the table is scrollable vertically as well.
- The *"delete last"* button deletes the last (left-most) measurement received.
- The *"delete selected (x)"* button deletes the selected columns, if there are any. The number within the brackets is the number of columns currently selected.

- Use a long tap to select or deselect a column. Selected columns have blue backgrounds.

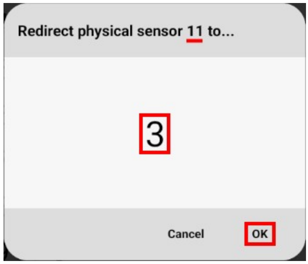
Settings view



- **Language:** shows the current language. Tap the name of the language to change it.
- **Email:** an optional email address you may be contacted by. This address is only shared with us when log files or an error report is sent.
- **Sensor redirections:** set or clear sensor redirections used while taking measurements (see: Configuring sensor redirections).
- **Project directory:** changes the directory where project files are stored. This starts the same procedure as the one that happened when the app was first installed (see: Project directory). You may wish to change it if the current directory is not visible when connecting your Android device to the computer via a USB cable (but other directories are).
- **Send log files:** sends the log files of the app. Please note that if you have an issue, just the log files on their own may not be enough for us to resolve it. Please consider also specifying your email address in case we have further questions about it. The best way of getting an issue resolved is contacting us via email or telephone.
- **About:** shows the application version.

Configuring sensor redirections

You can replace a damaged black box with a working one if you tell the app which one you removed and which one you moved. You can read a description of how sensor redirections work in the chapter: Testing and troubleshooting / Sensor redirections.



- Tap an item in the list to edit it.
- The *"Reset"* button clears all sensor redirections (the default state of the software).
- To change a redirection simply tap it. In the dialog that appears you can either tap the button to overwrite it, or spin it up/down to change it. The image to the right shows the 11 → 3 sensor redirection.

Opening Android projects on the PC

There are two main ways of transferring your Android projects to the PC:

- Connect your Android device to the PC using a USB cable and use the File Explorer on the PC to view the files of the device.
  - If you do not find your Android device in File Explorer, ensure that file sharing (also called "File transfer" or "MTP") is enabled in Android (instead of only charging it's battery) You may find an option for that by dragging down the top bar on Android.
  - If you do find other Android files and folders in File Explorer but not your ArborSonic3D projects, you may need to select a folder that is visible in File Explorer to as your project directory (see: Project directory). Note that changing the directory does not move the contents of the old folder to the new one. You may do so using the file manager app on Android.
- Use the Share button to pass the project file currently open to another Android app (see: Project view). You may use an email app (like Gmail) to send the project to yourself as an attachment. Other communication apps may be able to do something similar, while file manager apps may either be able to copy it to a network drive or web storage. Please note that not all apps are able to accept files shared this way.

Though the Android app saves project files with a ".f3dx" file extension, the PC software can open these just like regular ". f3d" projects.

Testing and troubleshooting

This chapter describes how to test your equipment. Please read this chapter carefully if you did not use your device for more than 3 months and you are planning to go to the field.

The most common troubles, errors and misuses are also described with the most probable solutions.

Testing before going to the field

- Please check if the battery is well charged. The Bluetooth connection needs much charge. (Sometimes even new and unused batteries don't have enough charge.)
- Hammer two sensors to any piece of wood. No tree is needed only a piece of wood.
- Connect the two sensors to one Amplifier Box and connect it to the Battery Box.
- Start the program on your computer and turn on the Battery Box.
- Check the COM port connection (as in the chapter Hardware – Bluetooth and serial connections).
- Go to the Time Data tab of the program and hit one of the sensors. If time data is arriving, these parts of the device are ready to work.
- If you cannot find any piece of wood, you can gently tap the sensor nails to each other and see if you get any new row on the Time Data tab.
- You may check all the Amplifier Boxes and sensors.
- The best is to have a tree nearby (in a garden or park) or a testing log and make a whole measurement similar to measurements done on field.

Connection issues

One of the most common issues is issues connecting to the Battery Box or Bluetooth Caliper. This usually results in the device either not appearing in the list of available devices, or the computer not receiving data from it. Here are the most common steps to resolving this:

- Ensure the device is turned on. Note that the Caliper automatically turns itself off after a while, and the Battery Box can quickly drain it's battery: it might have been fine when it was turned on, but if it was not fully charged it might have lost too much charge too much since then.

- Ensure batteries are fully charged. Low charges can cause spotty communication, or outright stop it. The light on the Battery Box starts blinking when the charge is low. Even if the light is not blinking, the reliability of the connection may drop as the battery charge drops. If your connection frequently breaks up it is worth it to see if switching to a fully charged battery helps.
- Ensure the Bluetooth device is close by. Bluetooth typically works reliably within a range of about 10 meters (30 feet). Walking too far away from the device will eventually drop the connection.
- Try the other COM ports (for Bluetooth Classic and USB cable only). Unfortunately you can connect to COM ports successfully even if they don't work. If you are trying to connect to the wrong COM port in he software, you will see a green status bar, and yet receive no data.
- Ensure there are no obstacles between the device and the computer (for Bluetooth only). The tree might stop the signal, if the Bluetooth device and the computer are on opposite sides of it.
  - Move one or the other side closer to each other (You can connect the Battery Box to any Amplifier Box, just make sure that all other Amplifier Boxes are connected to their neighbors.)
  - Similarly even if the computer and the device are placed on the same desk near each other, there might be issues if there is a metal cup between them or if the desk has metal parts.
- Be mindful of electromagnetic interference. The more Bluetooth devices are in the vicinity, the harder it is to connect and stay connected. Measuring trees close to power lines or the subway may also cause issues.
- Select the right device:
  - If using Bluetooth Classic, was the device paired with the computer? If not then it can not work until it is paired (see: Manual Bluetooth Classic device selection).
  - If using the USB cable for the Battery Box: did you plug it into the same port as you did the last time it worked? If not, then the COM port has changed and you need to select the right one. Try each one if there are multiple. Rarely even if you used the same port that worked previously, changing ports and selecting the device again resolves the issue.
  - Very common when multiple devices are shared among coworkers: if you did not pick up the same device that you used the last time then you are trying to connect to the wrong device. You will have to select the new device.

- If there are multiple devices available, did you connect to the right one? This may happen when measuring in parallel with a nearby coworker. Try at least temporarily turning off the others, and connect to the remaining device.
    - When it comes to Bluetooth Classic the COM port will appear in the list even if the device is turned off. This can be especially misleading if you picked up a different device that has not yet been paired: you will see the COM port of the old device in the list and might mistake it for the new one.
- If Bluetooth connections fail, try using the USB cable. If the cable does not work, try switching to using Bluetooth.
- Do not move Bluetooth dongles. If you are using an external Bluetooth module that can be plugged into a USB port (), then removing the module or moving it to another USB port can cause issues.
- As a last resort you may try these steps. They have infrequently helped resolve issues:
    - close the ArborSonic3D application on the PC, wait about 10 seconds and try again
    - turn off Bluetooth on your computer or Android device for about 10 seconds then try again
    - reboot Windows then try again

Common issues

- **Battery Box is not turning on:** Check the battery, charge or replace it with a fully charged one. Switch the unit on and off several times. (It is recommended to turn off the battery after each measurement and turn it on only for the duration of the measurement.)
- **No signal from any sensor:** Follow the steps described in the Connection issues chapter.

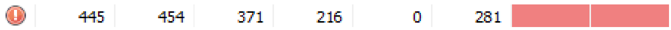
Measurement errors

	1 4	2 5	3 4	4 6	5 2	6 2	7 4	8 4
	394	495	530	542	473	254	0	227
!	390	486	2	530	466	250	0	221
	394	495	529	540	474	255	0	226

Errors with measurements are indicated by a red exclamation mark to the left of the time row in the *“Time Data”* panel, you may also see problematic cells highlighted by a red background. You can read a short error message about the issues found by moving the mouse above the red icon.

Once the issue is resolved, measurement errors can be deleted and the measurement should be repeated.

“Missing black box”



One of the black boxes or sensors did not send a signal:

- the black box/sensor may not have been connected
- the black box/sensor cables may not be property connected
- the battery may be low. Check that the battery indicator is green. Please replace the battery if the charge indicated is lower than 8V.

- bad sensor redirections may be enabled. You can turn of sensor redirections in the “Reader configuration” dialog (see: Opening the Battery Box selector).

“Missing sensor”

The black box that the sensor should be connected to reported that the sensor remained silent. The cause is likely similar to *“Missing black box”* errors: ensure the sensor is present and the cable from the sensor connects well to the black box. Check the battery and sensor redirections.

“Start sensor could not be determined”

The sensor hit could not be determined. This could be a bad hit on the sensor, or the tree trunk could have been accidentally hit or kicked. Movement or branches close to the sensors or of trains/trucks nearby may cause this as well.

“Measurement below lower threshold”

The measurement contains unrealistically small time values, unless the trunk diameter is smaller than 30cm or there are sensors closer than 3cm. The numbers 28 or 29 may indicate noise in the system and if the issue persists then the Amplifier Box may be faulty. Please contact Fakopp Kft., or your local dealer, about the issue.

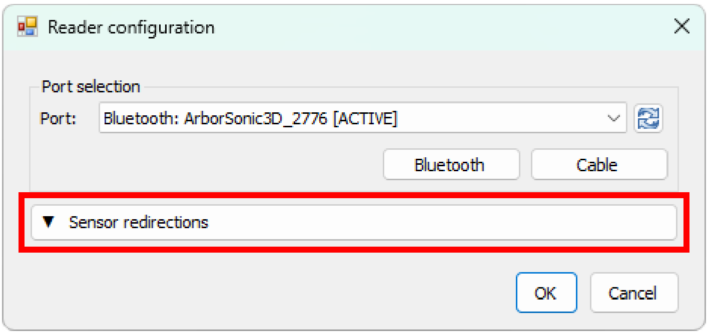
“Hit detected on multiple sensors”

Similar to *“Start sensor could not be determined” errors*, this is a bad hit to the sensor or vibration in the trunk from an external source.

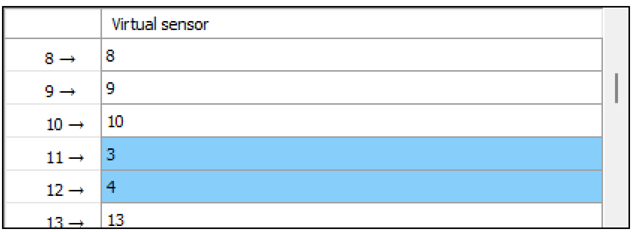
“Data count higher than selected sensor count”

The number of sensors sending data is higher than the sensor count specified in the “Sensor Geometry” panel. Increase the sensor count.

Sensor redirections



If one of your black boxes is damaged you can use another to replace it, however you have to tell the software which one you removed and which one you will use in a different position. Sensor redirections change which sensor a time measurement is stored for when a stress wave is detected. In the software they are represented by arrows between two numbers.



	Virtual sensor
8 →	8
9 →	9
10 →	10
11 →	3
12 →	4
13 →	13

- **X → X:** when both sides of the arrow show the same number, that indicates that no redirection is active. For example 3 → 3 indicates that the third sensor is connected to the plug marked 3 on the black box.
- **X → 0:** when the arrow points to zero, that indicates that the specified black box plug is not connected. For example 3 → 0 indicates that plug number 3 (on black box 3-4) is not connected to a sensor, and the software should not expect time measurements from it.
- **X → Y:** when both sides of the arrow show different (non-zero) numbers, that indicates that a sensor redirection is in effect. For example 11 → 3 indicates that plug number 11 (on black box 11-12) will be replacing plug number 3 (on black box 3-4), and that the third sensor should be connected to plug 11 instead of plug 3. Another way to read it is that plug 11 (on black box 11-12) will be receive data from the 3rd sensor instead of the 11th.

Keep in mind that reducing the number of black boxes in active use means that you have to specify a smaller sensor count in the layer geometry. You always have to connect a sensor to both plugs on every black boxes that you use.

Sensor redirection example

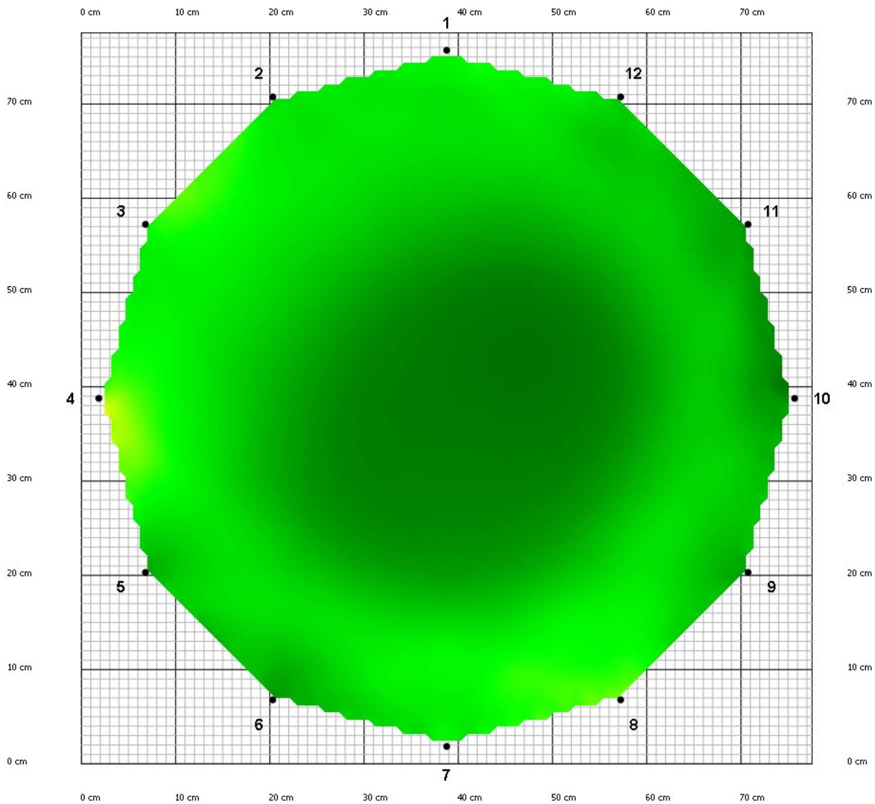
As an example let's imagine that you have identified that the black box 3-4 is damaged. You have 12 sensors and choose to replace it with black box 11-12.

1. You indicate that black box 11-12 is going to be placed earlier in the chain by setting the following redirections: 11 → 3, 12 → 4
2. Ensure that the black box 3-4 is not expected to be used (3 → 0, 4 → 0)
3. When specifying the layer geometry, make sure to use 10 sensors instead of 12 (since you are short a black box, you are unable to use a pair of sensors)

Common setup issues illustrated with resulting tomograms

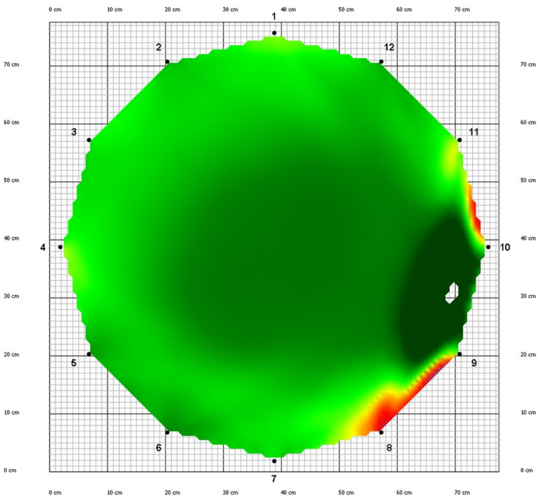
Device setup or program settings can cause strange tomograms. We collected the most typical cases. Note that some of the strange tomograms CAN refer to real decayed, damaged situations as well. The errors demonstrated were measured on a healthy tree and may look different on decayed trees.

A correct measurement looks like this:



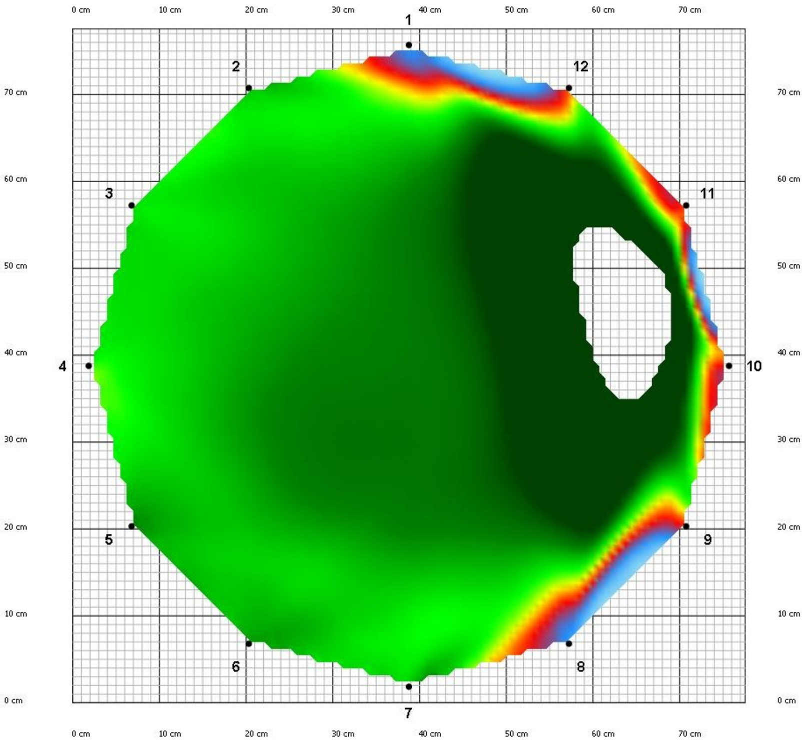
Crossed cables

As the sensor in the ninth position's cable was connected to the tenth connection on the Amplifier Box and the sensor in the tenth position was connected to the ninth connection. The tomogram contains a hole and red side areas.



Mixed-up Amplifier Boxes

The Amplifier Box for sensors 9 and 10 was exchanged with the Amplifier Box for sensors 11 and 12. The tomogram has a hole and strange areas on the side.

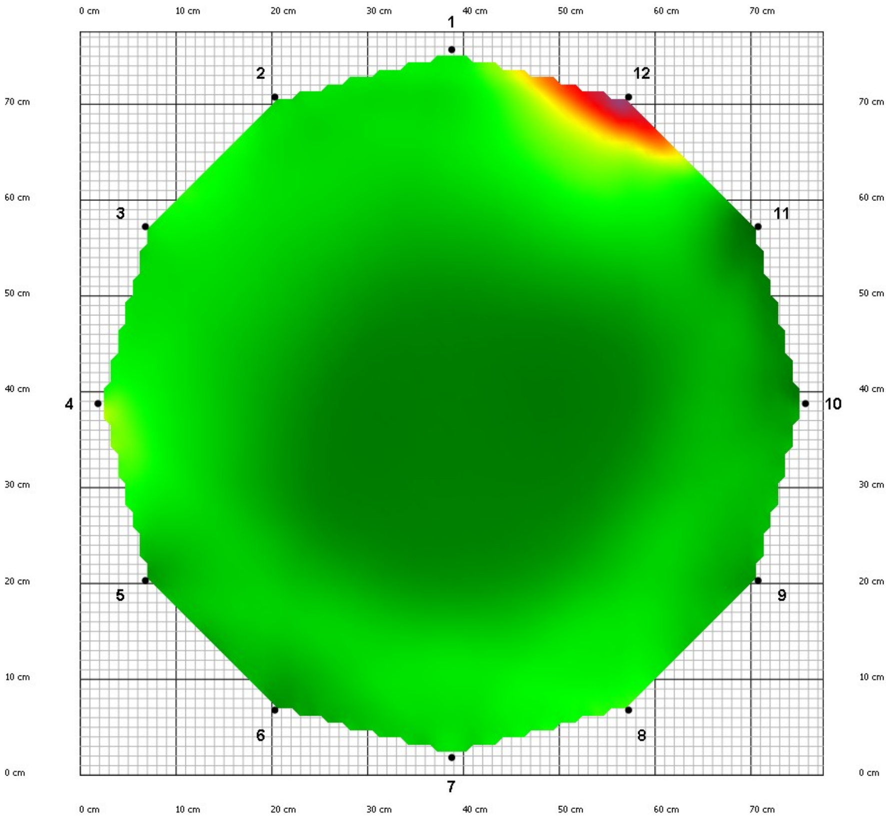


Loose sensors

Sensor 12 didn't penetrate through the bark. The sensor was very loose.

A damage-like area appears on the tomogram.

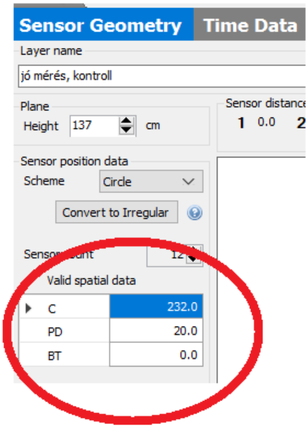
Note that a tomogram like this could also indicate decay or other issues.

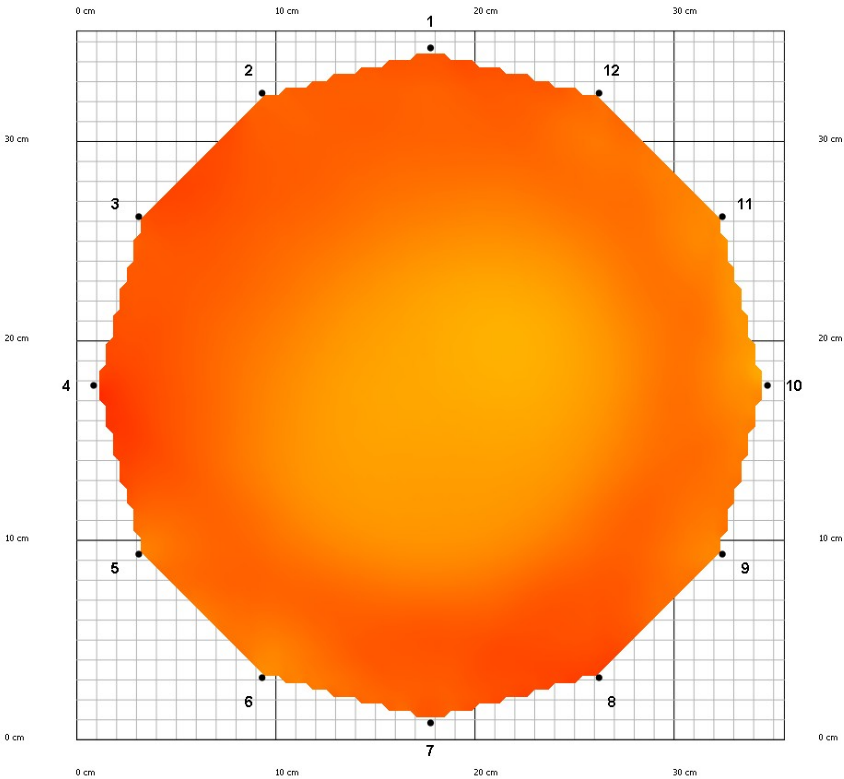


Extreme penetration depth

The penetration depth was set to 20 cm instead of 2 cm.

Even the tomogram of a healthy tree looks like if it was all decayed

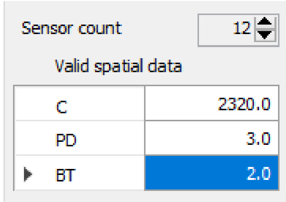


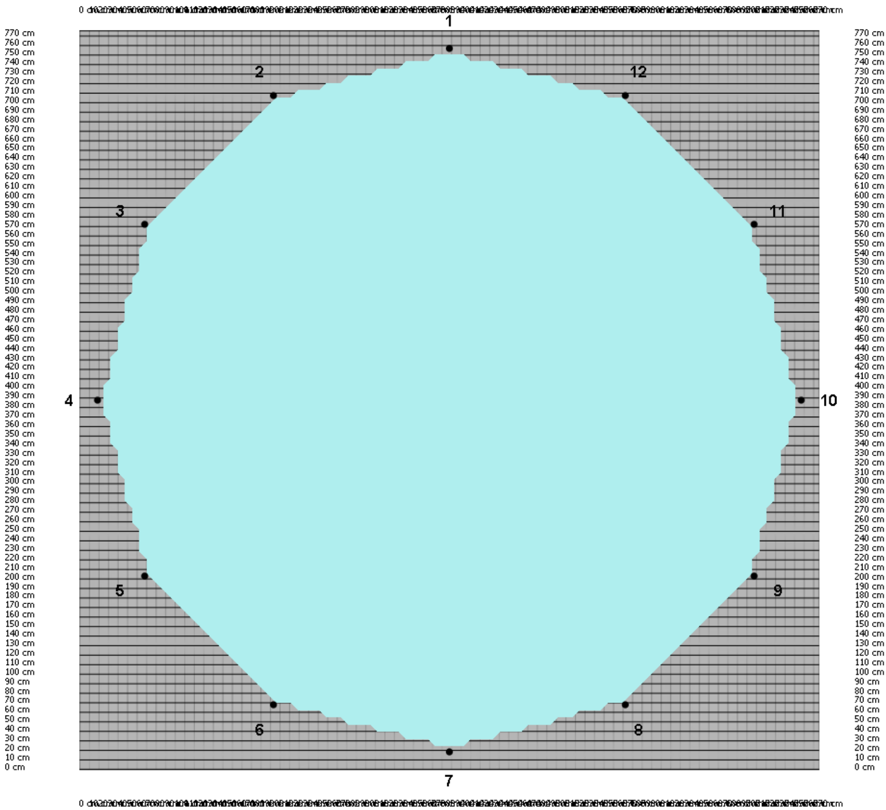


Extreme circumference

The circumference was set to 2320 instead of 232 cm.

The tomogram becomes light blue while the values on the axes become high.

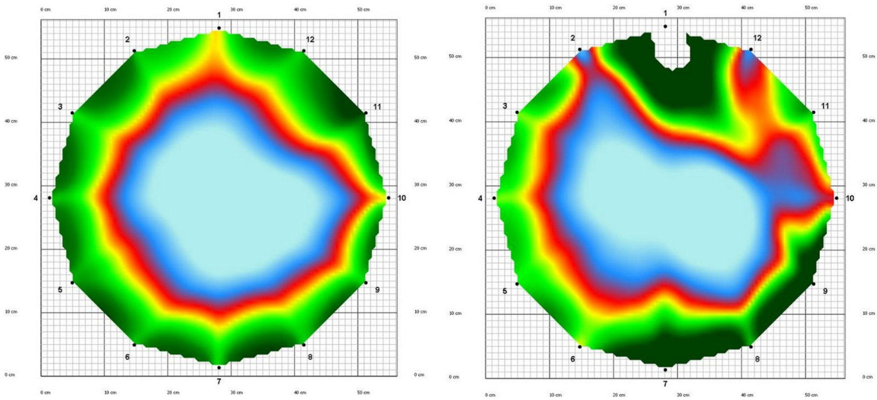




Tape measure left on tree

In this case an acoustic shortcut can appear. This issue was measured on a decayed tree to highlight the differences.

Measurement without tape measure (left) and with tape measure (right).



Miscellaneous advice

- Clean the device after measurement. Sterilize the sensors if there is a risk of transmitting fungal residue.
- Check the batteries before going to the field.
- Fix the sensors with the rubber hammer and generate sound signals for measurement with the steel hammer.
- If you expect to measure trees with elliptic or irregular trunk shape, it is recommended to bring a caliper as well.
- Do not use the device if the temperature is below 0 °C / 32 °F or more than 40 °C / 100 °F.
- Do not use the device in heavy storms, rainy conditions.
- Consider using a folding table for the laptop.
- Do not open the amplifier boxes or the sensors. If there is a problem with the device, please contact us. Opening the parts cancels the warranty.
- The device includes sensitive components, do not drop it, step on it, put it under water.
- Always save the data after the measurement.
- Keep the device in a dry place at room temperature.
- You may clean the device using slightly wet cloth.
- Clean resin from the sensors using rubbing alcohol.
- If any of the parts are broken please contact us.
- Coil the cables without a tangle .

FAKOPP

LONGNAILS APPENDIX

Longnails

Introduction

This appendix is for the users of ArborSonic 3D who measure with the long nailed sensors.

Normal sensors have 6 cm / 2.36 inch nails which are suitable for the most of the tree species, where the nails can reach the wood material. However, some species have thicker barks and longer nails are needed. The longer nails are 12 cm / 4.72 inch long.

The usage the long nailed sensors is mostly similar to the normal ones. This appendix contains and highlights only the cases where there is a difference.

Hardware

The maintenance, fixing, measuring and removing are the same as for the normal nailed sensors. Amplifier and Battery boxes are the same as are the cables.

Please do not mix normal and long nailed sensors for the same measurement.

The case is higher (and little heavier) to have enough space for the long nails to fit in.

For measuring the proper acoustic signals, the nail has to go through the bark and reach the wood material. You may have to hammer the sensors 10-11 cm deep.

Software

Application or Project Options

The ArborSonic 3D software needs to be configured to work with longnails, instead of the normal sensors. There are two ways to do this:

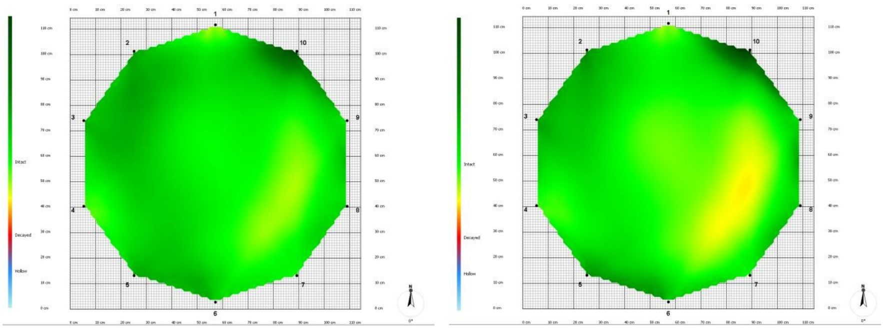
- If you are only going to work with longnails, you should change the type of sensors being used in the *“Application Options”* window (see Application Settings / New projects). This way each new project created afterward will expect to work with longnails.
- If you only occasionally use longnails, or switch back and forth between them and normal sensors, then you may prefer to leave the default sensor type in *“Application Options”* as *“Normal”*, and only change the sensor type for the current project in the *“Project options”* window whenever you are about to use longnails (see Tree / Project options).

Time data

Ensure the correct sensor type is selected from the *“Project options”* on the *“Tree”* panel. Afterwards you may perform the measurement as usual.

Tomograms and Biomechanics

The calculated tomograms are different according to the time correction used.



Tomograms for redwood (measured with long nails) calculated with *“Normal”* sensor type on the left, and *“Long”* sensor type on the right.

Using the wrong sensor type may lead to erroneous tomograms. (In the example above the tomogram on the left shows less decay than there actually is.)

As the extent of the decayed area and the severity of the decay are different in these cases, the safety calculations on the Biomechanics tab will be different as well.

(Similar effects appear if normal sensors are used for a measurement but longnails are selected as sensor type.)

LUDWIG SENSORS APPENDIX

Ludwig Sensors

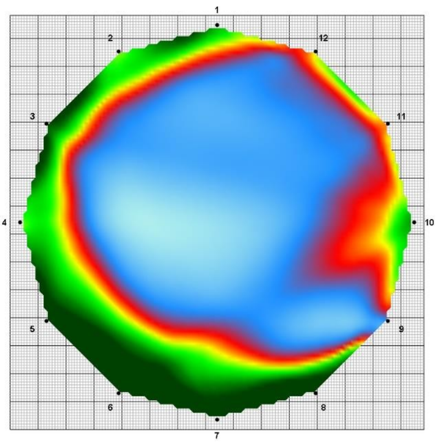
Introduction

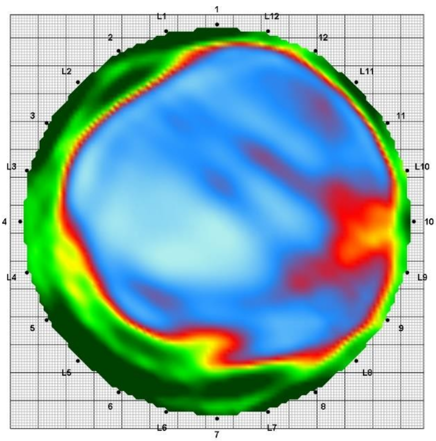
Ludwig sensors

- make more detailed measurements
- let you enter more precise geometry
- provide more precise tomograms

This appendix is for the users of ArborSonic 3D who measure with Ludwig sensors. Ludwig "sensors" are nails without sensors. They can be hit like sensors, making them signal sources, but they can not take measurements. (They are "deaf", still making perfect sounds.)

Using Ludwig sensors when used in addition to normal sensors can show a more accurate picture of the selected layer.





The images show the same measurement without and with Ludwig sensors.

On the geometry page is a "Ludwig sensors" checkbox (under "Sensor count"). When it is checked, Ludwig sensors are added to geometry and they behave like extra sensors. On the "Time Data" panel normal sensors should be measured first, as usual. After the normal sensors the Ludwig sensors should be measured in order (L1, L2, L3...).

The tomogram is calculated by the program and can be used for biomechanical calculations or for reports and so on. The steps are detailed in the chapters of this appendix.

Accurate evaluation is possible only if the 'blind' sensors are the same in both shape and material to the ArborSonic3D sensors. In case of using any other nails or using less than 10 Ludwig sensors, the time data is misleading the tomogram is unreliable.

Hardware and set up

Ludwig sensors are special nails (both in shape and in material) with a 6 cm long spike and a rounded head. The maintenance, fixing and removing are almost the same as for the normal sensors. Ludwig sensors can be easily removed with the remover tool.

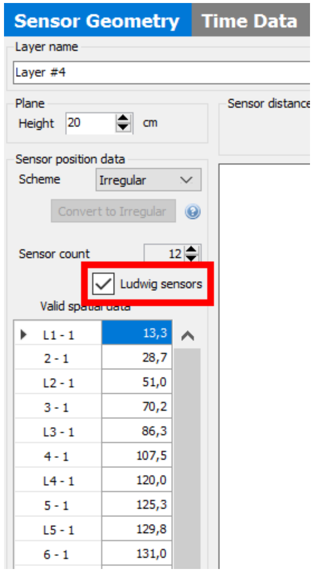
As Ludwig sensors are supplements only, they can NOT be used on their own, they have to be used together with normal sensors.

When measuring with Ludwig sensors, use the same number of Ludwig sensors as normal sensors. Always put one Ludwig sensor between 2 normal sensors (and one sensor between 2 Ludwig ones).

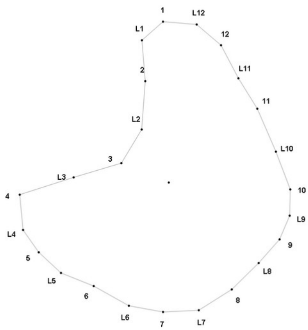
Hit the Ludwig sensors to the same depth as the normal ones are.

Geometries

- Check “Ludwig sensors” on the Geometry page
- If you use circular, elliptic or rectangular geometry, the software will show you where to place the Ludwig sensors. They will be L1, L2, L3,… on the geometry page



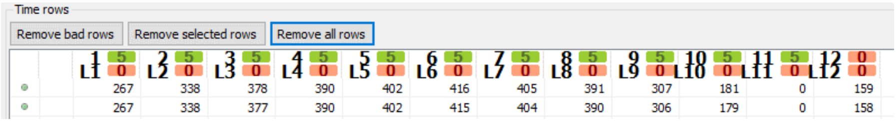
  - Distances will start with 1 for the first sensor, then L1 for the first Ludwig sensor, 2 for the second sensor and L2 for the second Ludwig one, and so on.
  - The number after the letter “L” is the number of the normal sensor to their left
  - Ln is always between normal sensors n and n+1. (Except the last one, which is between the last and the first sensors.)
- When using irregular geometry, you will have to measure the distances same as when you only have normal sensors, except you will have to measure the Ludwig sensors too. The software will tell you which distances to measure (ensure speakers are turned on).



An example for irregular geometry with 12 sensors and 12 Ludwig sensors

Measurement – switching between normal and Ludwig sensors

After setting the geometry click to the “Time data” tab to perform the measurement. In the “Time rows” table there will be an extra row at the top.

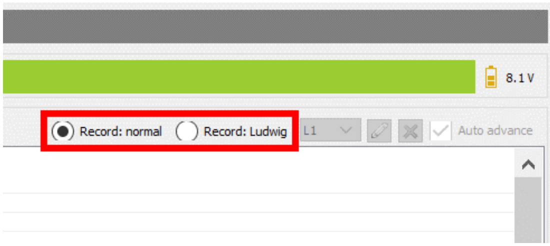


	1 L1 (5/0)	2 L2 (5/0)	3 L3 (5/0)	4 L4 (5/0)	5 L5 (5/0)	6 L6 (5/0)	7 L7 (5/0)	8 L8 (5/0)	9 L9 (5/0)	10 L10 (5/0)	11 L11 (5/0)	12 L12 (0/0)
●	267	338	378	390	402	416	405	391	307	181	0	159
●	267	338	377	390	402	415	404	390	306	179	0	158

Begin the measurement using only the normal sensors as you usually would.

In the top-right corner “Record: normal” should be selected. (This is the default.)

After all the normal sensors receive at least the minimum number of good hits, you can switch to “Record: Ludwig”.



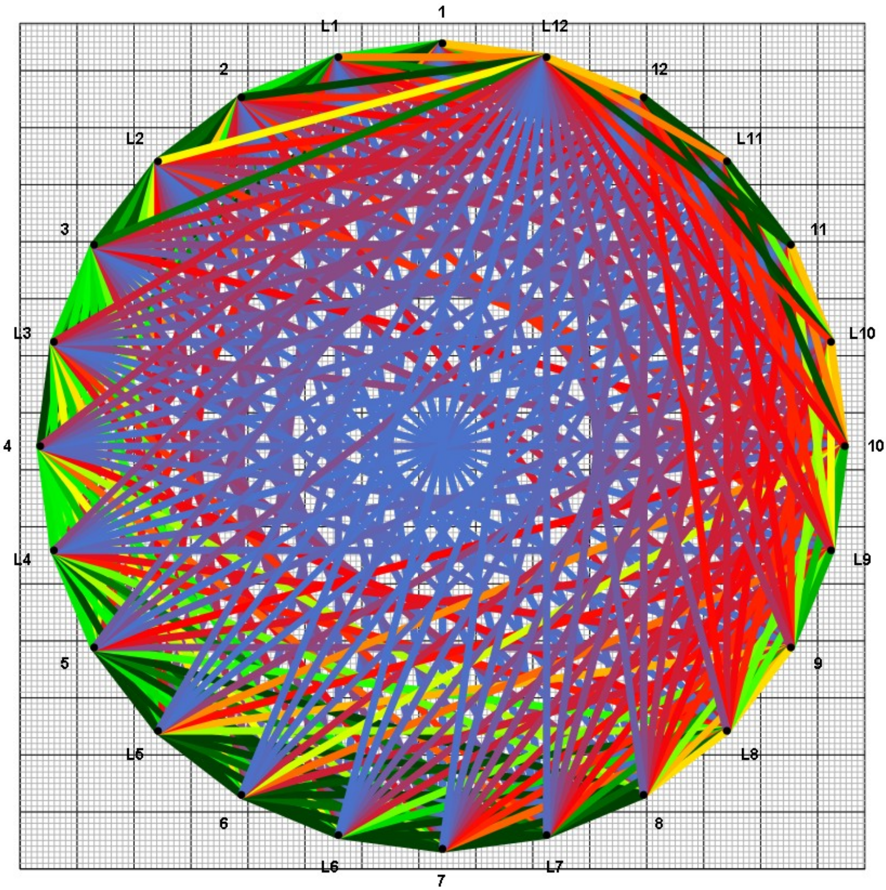
The software needs to be told which Ludwig sensor you are going to hit next. The easiest way to do this is to make sure that "Auto Advance" is checked. This way once you've made the minimum number of good hits on a Ludwig sensor, the software will automatically "advance" to the next Ludwig sensor. You will hear the name of the next Ludwig sensor to be hit when this happens.

The Ludwig sensors should be hit in order, starting with L1. Hit the Ludwig sensors’ heads similarly to the normal ones, with a loose wrist.

When you hit enough on the Ludwig sensors, the measurement is finished. (Turn off the Battery Box to save battery.) All the areas next to the sensors’ and Ludwig sensors’ numbers will be green containing the number of correct hits.

After a bad hit on a Ludwig sensor badly you will hear the usual sound indicating such. The same sound is played if you hit a normal sensor instead of a Ludwig one, or the other way around. (A normal hit can be changed into a Ludwig hit in the software, and vica versa. See: Time data corrections – what to do with a bad hit?)

Tomogram



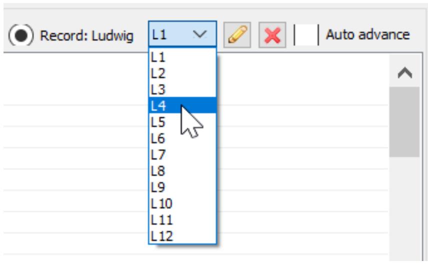
Tomograms function the same way as usual, with the only difference being that Ludwig sensors are shown as L1, L2 and so on.

The maximum number of normal sensors is 32, and the maximum number of Ludwig sensors is the same. Together the 32 normal and 32 Ludwig sensors can result in quite a few lines in the “Graph” view, as seen above.

Software – Number of required hits

For both normal and Ludwig sensors there is a minimum number of good hits required per sensor. When you reach this, the number in the column header turns green, and if this was a Ludwig sensor and Auto Advance is checked, you automatically advance to the next Ludwig sensor.

It is recommended to set this number between 3 and 6. You can do so via the “Project options” window (see: Tree / Project options)



If you want to measure more with one Ludwig sensor, you can do it manually by unchecking “Auto advance” and selecting the Ludwig sensor.

Time data corrections – what to do with a bad hit?

In case of a measurement error (red icon to the left), you can delete the time row as you normally would.

If the measurement itself is good but it indicates the wrong Ludwig sensor being hit, you can change the Ludwig sensor number: select the correct Ludwig sensor that was hit from the drop-down list, select the time row to be modified, and then click the button.

You can turn a normal sensor hit into a Ludwig sensor hit the same way (make sure that "Record: Ludwig" is selected).

You can also turn Ludwig sensor hits into normal sensor hits by selecting the affected time rows and clicking the button (make sure that "Record: Ludwig" is selected).

Hiding Ludwig measurements

If you are interested in how the tomogram would look like if the measurement was done using normal sensors only, you can go to the Sensor Geometry page and uncheck the Ludwig sensors box.

This hides the Ludwig sensors from the tomogram. You can always check "Ludwig sensors" to bring them back. You do not lose any data by hiding them.