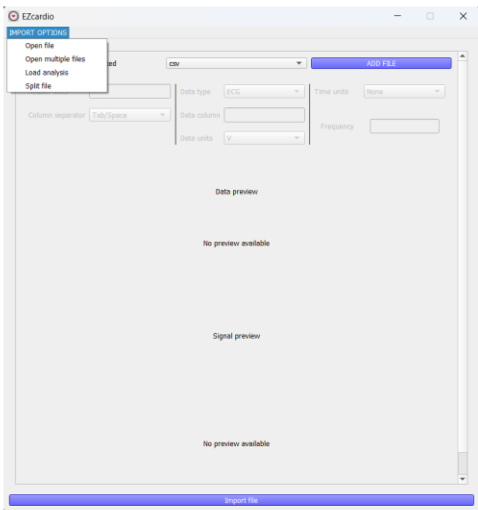
EZcardio

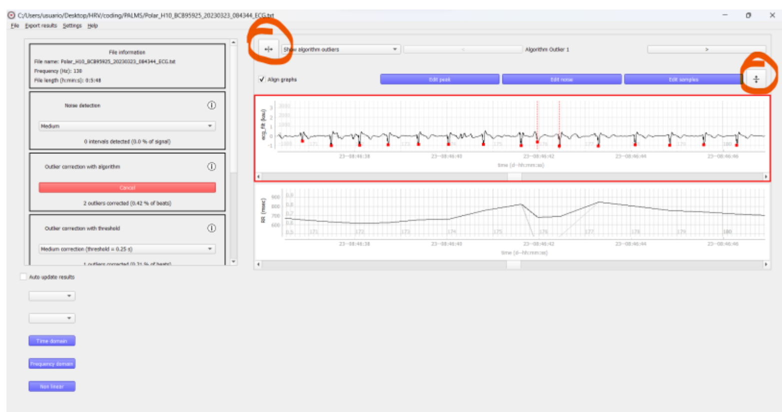
USER MANUAL

Contents

General view of the program

- The program has to main screens. The first one that appears is the import page, where we can specify the file and data we want to import. Then, we go to the main screen, where we perform the analysis and get the results. We can see these screens on the images.
- The image on the right is the main screen of the program. We can devise three sections. There is a column on the left where we have all the analysis options. On the right, we have the ECG and RR graphs and some options to manually edit them. And on the bottom, we can see the results.
- It is possible to expand the graphs on the right part to occupy a bigger part of the screen. We can do this with the expand buttons, which are highlighted on the image: left-right or bottom-up. The left-right one hides (or shows) the processing options on the left. The bottom-up one hides (or shows) the results.





Import page

Import possibilities

When importing a file, the default screen that appears lets the user choose a file that contains the signal and import it. However, there are different possibilities of importing data:

- Open multiple files.
  This is useful in cases where a long signal is recorded but there are some parts missing within it. So, you have different files that correspond to the same participant and the same trial, but they were split in different files because the connection was lost for a moment during the trial. Instead of importing each of these files per separate and doing the analysis with each, you can import all of them together. The time when there is not signal (that would be the lost recording between two consecutive files) is considered noise, so you also need to specify the datetimes when importing multiple signals.
  On the multiple files page, we can see the same page as in the single import but with arrows. These arrows let us select different files. We can choose the path of the first file and set the import options (data column, data type, …). Once this is done, we can click on the ">" arrow and we will see a new import page, but empty again. We can choose a new file and the options will be automatically filled with the same options that the first file had (although the options can be set for each file if the user wants to).
- Load analysis.
  EZcardio has the option of saving the current analysis you are doing. In case you need to continue analyzing a signal at a later moment, you can save it so you do not need to start it again next time. When loading this previous analysis, every previous modification is kept, including manual or automatic annotations. In case you are checking noise intervals or outliers, it will also open from the last noise or outlier that you saw the previous time you were analyzing the signal. Saved analysis are stored in h5 files to reduce the time needed to load them again and reduce memory consumption.
  When we select this option, the directory will open and we just need to select the h5 file where the previous analysis is saved.
- Split file.

Some signals can be very long and make the program work slowly. It is not recommended to load signals that last more than a day, as the program will be slow and can crash.

On this page, we see the same page as in the single file import, but now we need to specify the number of output files we want. We will just get the data and time (if indicated) columns, so we also need to specify them. The output files will have the same name as the original one, with "_splitx" added after their name, where x is the number of the new file.

File types and options

EZcardio currently support the import of any numerical data file (csv, txt, dat or any other file that has a delimiter) and some other files that can include ECG data, like edf, ecg, hea and fit. Before selecting the file path, the type must be selected.

Once we select the type and the path, we will see the data preview. For numerical data files, we see the full table that is inside the file. For the other file types, the program will read all the headers that appear inside the file and show the column that is associated with each header. By seeing the data preview, we can choose the import options. These help the program understand where the data is in the file. For the numerical data files, we specify a delimiter and a header. From the delimiter the columns in the data are set, you we can also indicate the index of the data column and the index of the time column. There are different time formats to select, so we can specify the time in seconds, milliseconds or many datetime options. In case we do not import a time column, we must specify the frequency of the signal (in non-numerical files, the frequency will be filled automatically if found in the file). For the non-numerical data files, we also need to specify the index of the data column, considering the order in which they appear in the data preview.

The other import options that appear are the data type (ECG or RR) and units. It is recommended to import ECG, as it shows more information, and the analysis is likely to be more accurate. But it is also possible to just import RR values. Also, it is important to set the proper data units, as the program can give an error if this are not properly set.

When we specify the proper data and time columns (or data column and frequency), we will see a signal preview on the bottom. With this preview we can confirm that the options we chose are correct and click on "Import Data" to open the program. If we do not see the signal preview, there is likely to be something wrong on the options we chose.

Signal display

Graphs: ECG and/or RR

On the top right part, we can see the ECG signal (if included) and the RR intervals. At these graphs we will see all the modifications that we do in the signal, whether they are done with one of the automatic analysis options or manually.

In case we have both graphs (not just RR), we see a checkbox that says “Align graphs”. With this, we can specify if we want both graphs to show the same interval or have a different interval each. When this box is checked, scrolling or zooming on one of the graphs will scroll or zoom on both graphs. While when the box is unchecked, scrolling or zooming on one of the graphs will scroll or zoom just on the graph we are using, while the other graph will not change. If graphs are not aligned, we will see a highlighted region on the RR graph that represents the current displayed interval in the ECG graph.

We can set the interval of the graphs with the slider that each has on the bottom, but also directly from the graph. By using the wheel on the mouse or double fingers on the keypad, we can easily zoom in or out.

On the ECG graph, we see red circles that represent the beats. This are also reflected on the RR graph, that is automatically measured from the circles on the ECG. If we have done some preprocessing, we can also see two different lines on the RR graph. The normal black one represents the current RR considering the processing options (including automatic and manual). There might be a lighter line that represents the original RR values, before any outlier correction. This way we can contrast our current analysis with the original annotations.

Markers

Above the graphs we can see two other rows. The first of them, where the left-right expand button is, shows the markers. The markers are used to locate all the noise or outliers that the program has automatically detected. We have a combo box on left where we specify what we want to mark (noise, algorithm outliers or threshold outliers). On the right, we can select the index of the noise or outlier that we want to see. This way, we do not need to go through all the signal to find where there is a part we need to correct. But we can just go to the next marker and we will directly see the interval where it happens. The marked noise or interval will appear on the middle of the screen. If it is noise, it will be a black rectangle that will hide the signal (we can virtually see the signal again by moving the mouse on the rectangle). If it is an outlier, it will be indicated in the signal with a vertical red line.

Manual processing options and shortcuts

On the second row, where the "Align graphs" checkbox is, we also see three buttons that let us manually process the signal. We have three manual processing options: peak annotation, noise selection or sample selection. These buttons are blue by default and one will become red when we press it, so it will activate the indicated processing option. Peak editing and noise selection should be done on the ECG graph, while sample selection works on the RR graph. In case just the RR graph exists, we can do any option on it.

- Peak editing. On the ECG graph we see the detected peaks as red circles. These are also reflected on the RR graph, where we see the intervals measured from the circles on top. We have four possible ways of editing peaks. We can add a missing peak (left click), delete an existing peak (right click), add an interpolation (CTRL and left click) or delete an interpolation (CTRL and right click). Interpolations are done by changing the RR value by the mean of the previous and next 5 values.
- Noise selection. If we specify a part of the signal as noisy, it will not be considered on the analysis. The signal will be hidden behind a black rectangle (it can be virtually seen by moving the mouse to the rectangle), that can also be edited. The options we have to set the noise are adding a noise interval (CTRL and left click), deleting an existing noise interval (CTRL and right click), moving a noise interval (SHIFT and left click in the middle of the interval and moving to new location) and moving one of the extremes of the noise interval (SHIFT and left click in the extreme of the interval and moving to new location). If we create a new interval, it will have a default size, but we can change it with SHIFT and moving it how we want.
- Sample selection. To manually add or delete a sample, we need to have already added samples with the automatic option. This is because the sample must have a name. So, we can add a group of samples with the sample options on the left part of the interface, and then modify them. The options and shortcuts are the same as for the noise intervals. In case we do not have any group samples added, we can also use CTRL and left to set the start of the samples group, which will be set on the sample option.

Automatic processing tools

On the lest part of the screen, we can see all the options we can include in our analysis. On top, we see some basic information of the file, including the path, frequency and duration. After that, we see the analysis options, which are noise detection, outlier detection (that can be done with a special algorithm and/or with a threshold-based method) and the samples selection.

Noise detection

The goal of noise detection is to identify which parts of the signal do not reflect ECG and have to be ignored on the analysis. The idea to detect noise is to find the outliers and consider noise intervals the intervals where there are many outliers. There are different noise levels we can apply. In the main screen we can just see the level, but on the settings page we can also see what these levels mean and even design a custom noise level by specifying the desired properties. A noise level candidate is an interval of certain number of beats in which there are at least 3 outliers, in which a beat is considered as outlier depending on the selected method (outlier levels are explained in the next subsections). The noise level specifies how many beats there must be between 2 outliers so they are considered on the same interval and what the ratio of outliers the interval has. Each noise level means:

- Very low
    - Outliers are specified with a threshold of 0.45 seconds. If the RR value is more different than the mean of the 10-surrounding-beats interval in 0.45 seconds, it is an outlier.
    - 2 outliers are considered on the same interval if there is 15 or less beats between them.
    - The minimum outlier ratio of the interval is 0.4 or higher.
- Low
    - Outliers are specified with a threshold of 0.35 seconds. If the RR value is more different than the mean of the 10-surrounding-beats interval in 0.35 seconds, it is an outlier.
    - 2 outliers are considered on the same interval if there is 25 or less beats between them.
    - The minimum outlier ratio of the interval is 0.35 or higher.
- Medium
    - Outliers are specified with a threshold of 0.25 seconds. If the RR value is more different than the mean of the 10-surrounding-beats interval in 0.25 seconds, it is an outlier.

        - 2 outliers are considered on the same interval if there is 35 or less beats between them.
        - The minimum outlier ratio of the interval is 0.3 or higher.
    - High
        - Outliers are specified with a threshold of 0.15 seconds. If the RR value is more different than the mean of the 10-surrounding-beats interval in 0.15 seconds, it is an outlier.
        - 2 outliers are considered on the same interval if there is 45 or less beats between them.
        - The minimum outlier ratio of the interval is 0.25 or higher.

After the noise has been detected, we will see in the text label how many noise intervals have been detected and what percentage of the total signal they represent. We can see each of these intervals with the markers.

Outlier detection with algotihm

There are two ways of detecting outliers: with a special algorithm and with a threshold-based method. When choosing one of these methods, the RR values are set to the original ones that were set when loading the file. This means that previous outlier detection that was used will be deleted, but also any previous manual peak annotation will be ignored. Then, it is recommended to use the outlier detection methods before manually editing peaks.

The special algorithm is the one that kubios founders invented. It is based on different thresholds and average windows and it also determines the kind of correction needed, so if there is a peak missing, an extra one or an interpolation needed. A more detailed explanation can be seen in the Appendix. With this algorithm, we just need to specify if we want to use it or not. We see a text label saying how many outliers were detected and what percentage of the total number of beats they represent. We can see each of the outliers with the markers.

Outlier detection with threshold

The other outlier detection method is the one that uses a threshold. This method, if active, is always used after the algorithm correction. So, if the algorithm is active, the threshold outliers are detected from the RR values corrected with the algorithm. Otherwise, just from the original values.

We can choose different threshold levels for this method:

- Very low. Outliers are specified with a threshold of 0.45 seconds. If the RR value is more different than the mean of the 10-surrounding-beats interval in 0.45 seconds, it is an outlier.
- Low. Outliers are specified with a threshold of 0.35 seconds. If the RR value is more different than the mean of the 10-surrounding-beats interval in 0.35 seconds, it is an outlier.
- Medium. Outliers are specified with a threshold of 0.25 seconds. If the RR value is more different than the mean of the 10-surrounding-beats interval in 0.25 seconds, it is an outlier.
- High. Outliers are specified with a threshold of 0.15 seconds. If the RR value is more different than the mean of the 10-surrounding-beats interval in 0.15 seconds, it is an outlier.
- Very high. Outliers are specified with a threshold of 0.05 seconds. If the RR value is more different than the mean of the 10-surrounding-beats interval in 0.05 seconds, it is an outlier.

We see a text label saying how many outliers were detected and what percentage of the total number of beats they represent. We can see each of the outliers with the markers.

Sample selection

In order to get the results, samples must be selected. We have the option of creating a group of samples instead of adding them one by one. We need to specify the following properties:

- The time where the first sample in the group will start (by default it is the start of the signal).
- The duration in format hour:minute:second.
- The number of repetitions that we want to create. We can also specify the end of the sample group (which can be the end of the signal), so samples of the indicated duration will be created until reaching that time.
- The overlap or time between samples.
- The minimum size in seconds. Samples are always created with the indicated duration and they can have a noise interval inside, which will be ignored. So, we will get an effective size in the sample, which is the duration of the RR intervals we use (ignoring the noisy ones). We can set a minimum here of how big this effective interval needs to be.

Once we have specified all the properties of the group, we need to click on the button "ADD" to create the samples. We will see them in blue on the RR graph. We can create another samples group if we click on the ">" button. Just the samples of the current group are shown on the RR graph.

Results view

When we have already created samples, we can start getting the results. We have the option of visualizing the results in the program before exporting them. On the left, we can see two combo boxes to choose the sample group and sample index of which we want to see the results. We can see time, frequency and nonlinear results. These results are gotten from the detrended RR values (with the exception of mean RR and the HR values.

Time results

We see a table with the most important time results and a histogram of the RR values. The table has the following values:

- Mean RR. Mean of the RR values.
- SDNN. Standar deviation of the RR values.
- HR values: mean, maximum, minimum and standard deviation. They are computed from the the average every certain number of beats and the non-detrended RR values.
- RMSSD: root mean of squared RR values.
- NNXX: finds number of RR values greater than a specified threshold XX and the ratio between number of intervals > threshold and the total number of NN interval differences.
- pNNXX: inverse of NNXX.

There are also some geometrical results on the table:

- HRV triangular index: ratio between the total number of NNIs and the maximum of the NNI histogram distribution.
- TINN: baseline width of the RR histogram evaluated through triangular interpolation.
- Stress index: following the equation

$$\mathrm{SI} = \frac{\mathrm{AMo} \times 100\%}{2\mathrm{Mo} \times \mathrm{MxDMn}}$$

where AMo is the so-called mode amplitude presented in percent, Mo is the mode (the most frequent RR interval) and MxDMn is the variation scope reflecting degree of RR interval variability.

Frequency results

The frequency results are the same independently of the method used. On the screen, we see the results based on the Welch or the Autoregressive method. In the settings we can specify that we want to use the Lomb-Scargle method instead of the Welch one.

We can see a graph with the frequencies distribution. These frequencies can be modified by the user. By default, they are:

- Very low frequency: from 0 to 0.04 Hz.
- Low frequency: from 0.04 to 0.15 Hz.
- High frequency: from 0.15 to 0.4 Hz.

The results that are reported for each frequencies interval are:

- Peak value: point with highest frequency. In Hz.
- Power: total density. It is reported in ms2, log, percentage, nu and a ratio between high and low frequency.

Nonlinear results

The non linear results are based on the Poincare graph and the Detrended Fluctuation Analysis. We can see two different graphs, one corresponding to the Poincare plot and the other to the Detrended Fluctuation Analysis. They include the following results:

- Poincare SD1. On the Poincare plot, it is the standard deviation of the data series along the minor axis. It is computed as the standard deviation of the SDSD parameter of the Time Domain.
- Poincare SD2. On the Poincare plot, it is the standard deviation of the data series along the major axis and is computed using the SDSD and the SDNN parameters of the Time Domain.
- Ratio SD2/SD1
- Approximate entropy. Measures the complexity or irregularity of the signal. Large values of ApEn indicate high irregularity and smaller values of ApEn more regular signal.
- Sample entropy. Same goal as Approximate Entropy, but using a different calculation.
- Detrended Fluctuation Analysis: alpha 1. Short-term fluctuations.
- Detrended Fluctuation Analysis: alpha 2. Long-term fluctuations.

Menu options

On top of the interface, we see a menu with some options

File

We can open a new file. When doing this, the program will ask if we want to save the current analysis. We can also decide to save the analysis with Save or Save as.

Results

To export the results, we have the option of creating a new file or append to an existing file. Appending the results to an existing file is intended to be useful when we had a long signal that we needed to split in smaller segments. To get the results, we can append all of them in the same file. This way, although we work with different ECG files, at the end we have all the results included on the same csv. For the first file that we analyze (or in case we just have one file with all our signal), we can choose the option of creating a new file.

Settings

When we select settings, a new window will appear in which we can set some default values for the analysis, as well as extra properties that cannot be changed on the main screen. In the settings page there are four sections:

- Pre-processing
  - Noise detection. We can choose the default detection level, that will have default values. If we choose the custom option, we can modify the values ourselves. These values are the ones explained on the noise detection section: outlier level, space between beats and noise ratio.
  - Algorithm. If by default the algorithm will be active or not.
  - Outlier threshold level. Default threshold level.
  - Detrending. It is applied to the RR values before getting the results and its goal is to avoid stationary problems with the results. Detrending is finding a constant function on the signal and subtract it, so we just get the non stationary trends. This can be done with polynomial functions of different orders or with smoothn priors. In case we use smoothn priors, we also need to specify the smoothn parameter.

- Analysis options. Default values for the sample selection, like the number of samples, sample length and minimum effective data on the sample. We can also specify the default value of the auto update results option.
- Time-frequency options
  - Time domain. The average number of beats that will be used to compute the HR values and threshold used to measure NNXX.
  - Frequency bands used for the frequency results.
  - Points to compute FFT.
  - FFT spectrum properties for Welch periodogram: order of moving average filter and if Lomb-Scargle will be computed instead of Welch.
  - AR model order for the autoregressive frequency results.
- Nonlinear:
  - We can choose whether we want to apply detrending or not for the nonlinear results.
  - For the entropy values, we can specify the embedding dimension and tolerance.
  - DFA: range of beats that will be used as intervals for the short and long term fluctuations.

Information

We can open the manual or a pop up window with the shortcuts.

Reported bugs

Open a new file in Mac

When doing an analysis with one file we can click on "Menu -> File -> Open new file" and we should see the import page again. This works in Windows, but on Mac it just closes the program.

Grid on second screen

When working with a second screen and the program is on the second screen, the grid disappears, although the annotations and axis are still correct.

Scrolling with keypad

Scrolling with the keypad (double fingers) makes the graph zoom, while is should move the current window.

Slider not completed when full signal

When zooming out to see the full signal, the slider does not show a full range, but it misses the first part.

Not fully aligned segments

There can be not very important issues similar to the last one. For example, noise takes a bit to adapt to the exact interval where it is when zooming out.

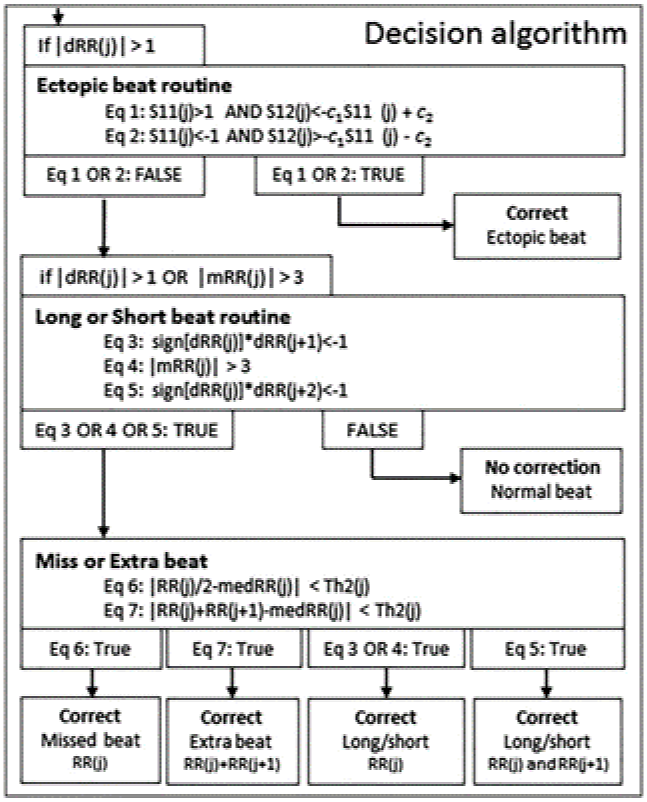
Appendix

Analysis recommendations

The recommended processing steps should be in the same order as shown in the interface: noise detection -> outlier detection with algorithm -> outlier detection based on threshold. It is also ideal that, after each of these steps is automatically done, the user checks the markers and does any manual modification that is needed. This can potentially help the next processing steps and reduce the later manual changes.

Outlier detection with algotihm explanation

The algorithm used follows the steps:



Decision algorithm
If |dRR(j)| > 1
Ectopic beat routine
Eq 1: S11(j)>1 AND S12(j)<-c1S11 (j) + c2
Eq 2: S11(j)<-1 AND S12(j)>-c1S11 (j) - c2
Eq 1 OR 2: FALSE
Eq 1 OR 2: TRUE
Correct Ectopic beat
if |dRR(j)| > 1 OR |mRR(j)| > 3
Long or Short beat routine
Eq 3: sign[dRR(j)]*dRR(j+1)<-1
Eq 4: |mRR(j)| > 3
Eq 5: sign[dRR(j)]*dRR(j+2)<-1
Eq 3 OR 4 OR 5: TRUE
FALSE
No correction Normal beat
Miss or Extra beat
Eq 6: |RR(j)/2-medRR(j)| < Th2(j)
Eq 7: |RR(j)+RR(j+1)-medRR(j)| < Th2(j)
Eq 6: True
Eq 7: True
Eq 3 OR 4: True
Eq 5: True
Correct Missed beat RR(j)
Correct Extra beat RR(j)+RR(j+1)
Correct Long/short RR(j)
Correct Long/short RR(j) and RR(j+1)