ECG VISUALIZER

USER MANUAL

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0. GETTING STARTED

The ECG Visualizer software is a tool that allows you to load XML files generated by a professional 12-lead ECG, visualise its content (being able to browse it), apply customised filters on the signal (being able to observe the result in real time) and generate a report of the detected characteristics of the signal.

All this with the possibility of a total configuration by the user, allowing to indicate which filters to apply and when, the characteristics of the patient whose ECG we are processing and the characteristics that we want to be included in the final report.

Currently supports the electrocardiograph CardioSoft 12SL from General Electric, but soon it will support also the Contec 1200G device.

The importance of this tool lies in the fact that healthcare professionals usually work with the printed signal provided by the electrocardiograph itself and do not usually make use of the digital report. This means that manufacturers do not provide powerful tools to process this information. Moreover, there are other tools made by third parties for other electrocardiographs but, in the case of the one used in this work, the existing ones do not correctly recognise the input files.

In the following sections, a brief explanation of the filters that can be applied with this tool, the features that can be extracted for the final report and the differentiation of patients (very important to correctly detect ECG signal peaks) will be given. After that, the mechanism to process the signal and all the options included in this tool will be detailed.

1. FILTERS

This tool implements from scratch 4 basic filters to be applied on all ECG leads equally (it does not allow application on a single lead).

These four filters are: average filter with fixed window, average filter with sliding window, median filter with sliding window and band rejection filter.

These filters are detailed below:

- Fixed-window average filter: the average value of the signal within a given window width is calculated. This filter does not include overlapping and therefore the signal is divided into blocks of size the width of the window to finally obtain a signal with a lower number of samples (number of original samples divided by the width of the window).
  Therefore, it can be seen in the application that applying this filter causes a reduction in the sampling hertz of the signal.
  This filter removes the digital noise from the sampling.
- Sliding-window average filter (or *moving average filter*): as with the previous filter, the average value of the signal within a given window width is calculated. However, on this occasion, signal overlapping is performed so that, after each calculation of the mean, the next calculation is performed with the same window but shifted one sample forward.
  This causes each mean calculation to include all the samples of the previous calculation except the oldest one (adding a new one in its place). This causes the number of samples to only be reduced at its final margin by N-1 samples (N being the size of the window); thus practically the original number of samples is maintained.
  This filter removes the high-frequency and low-frequency ripples.
- Sliding-window median filter (or *moving median filter*): it works in exactly the same way as the previous filter with the difference that, this time, the median operation is applied over the sample window (instead of the average).
- Band-rejection filter (or *band-stop filter*): periodic samples are removed with a repetition of a frequency determined by the user. Since the frequency is usually not exact, this band rejection is applied to the base frequency ± 5 Hertz.
  This filter is especially useful if we know certain frequencies that are introducing noise to the original signal, such as the frequency of the alternating current produced by the mains connection (50 or 60 Hertz depending on the continent).

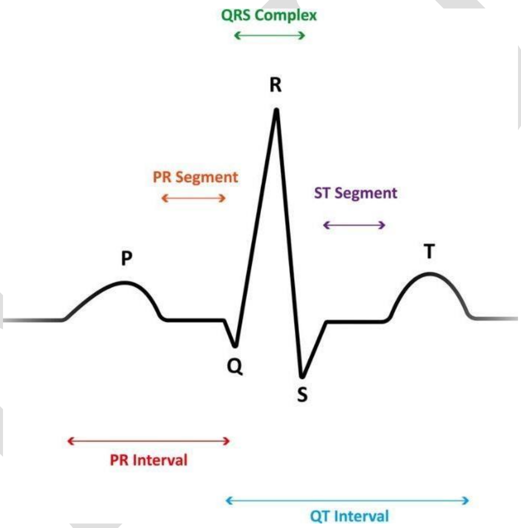
2. ECG CHARACTRERISTICS

An electrography signal represents the voltage variation of electrical activity caused by the heart.

Depending on where the electrodes are placed, attention can be focused on a particular type of activity.

For a professional measurement, 12 pairs of electrodes are used in order to see the 12 characteristic leads of the heart's electrical activity.

However, the signal collected from all leads has similar characteristics. They are all formed by the repetition of a characteristic pattern, which alludes to a contraction and expansion of the heart. This pattern is represented by certain peaks which are numbered with letters starting with "P". In this way, P, Q, R, S and T peaks are labelled in each repetitive pattern, as can be seen in the picture below:



Therefore, the electrocardiac characteristics of a patient are determined by the segments formed between these peaks.

Furthermore, these segments vary depending on the physical characteristics of the patient, with significant variations found in those with more developed musculature around the heart (usually professional athletes).

As a result, the ECG Visualizer tool performs peak detection taking into account these characteristics and the type of patient who has provided the ECG. This is configurable from the tool itself and will be discussed later.

3. FEATURES

The features extracted from an ECG signal are centred on the repetition of patterns and the average distances of the different segments of the signal for each lead.

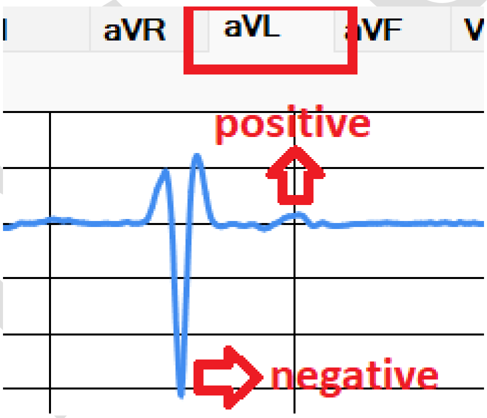
Therefore, considering the figure on the previous page, the distances of the following segments could be extracted: PQ, PQR, PQRS, PQRST, QR, QRS, QRST, RS, RST, ST.

In addition, it is common to measure the average distance between intervals of different patterns, known as the RR segment (the inverse of which is the pulse rate).

In addition, there are other features of the signal that are useful for the detection of certain cardiac abnormalities, such as the polarisation of the signals or of certain peaks within the signal.

In this respect, T-wave inversions are of particular interest since, if their polarisation is different from that of the corresponding R-peaks, they may pose certain risk factors for the patient (depending on the patient's condition).

An example of this case can be observed in the next image:



Here, a T-wave inversión of aVL leed is detected, as que R peak is negatively polarized and the T peak is positive.

In this tool, the user can select which characteristics to calculate to include in the final report. This process will be shown later in this document.

4. TYPE OF PATIENTS

Depending on the physical characteristics of a patient, the times of the various segments that form the ECG signal may vary.

In a typical patient without any cardiac abnormality, the PR interval usually takes between 120 and 200 milliseconds, the QRS interval takes between 80 and 120 milliseconds, and the QT takes between 350 and 430 milliseconds.

These intervals vary in elite athletes until they reach a value between 200 and 400 milliseconds for PR, between 80 and 160 milliseconds for QRS, and between 320 and 560 milliseconds for QT.

These values have been obtained from the work "*International Recommendations for Electrocardiographic Interpretation in Athletes*" (2017) from the *Journal of the American College of Cardiology* (https://www.sciencedirect.com/science/article/pii/S0735109717302024) and from the reference https://www.nottingham.ac.uk/nursing/practice/resources/cardiology/function/normal_duration.php for the case of the normal intervals.

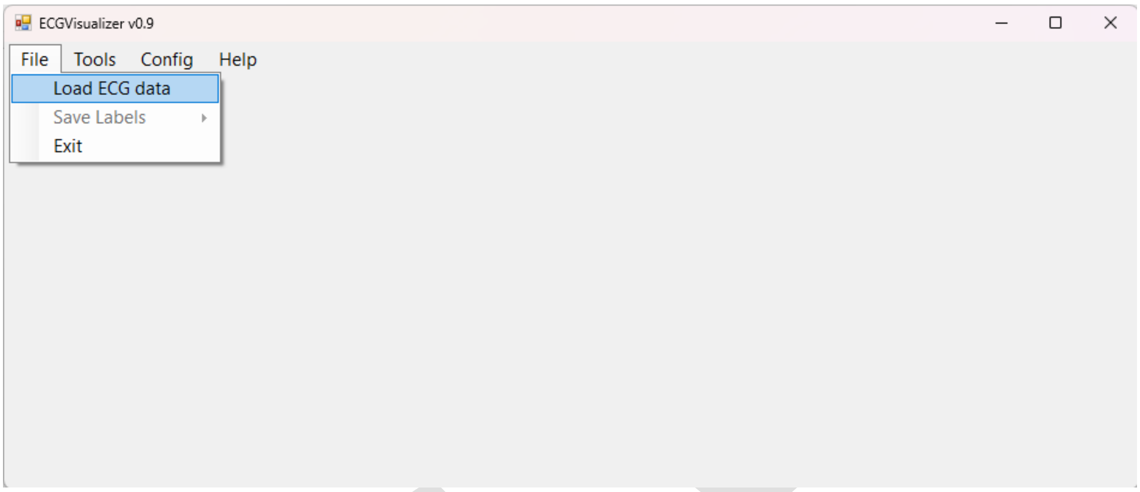
Even so, as the tool user can contemplate other non-standard cases, the software developed allows these three intervals to be defined in a completely personalized way.

This could be observed in the next section.

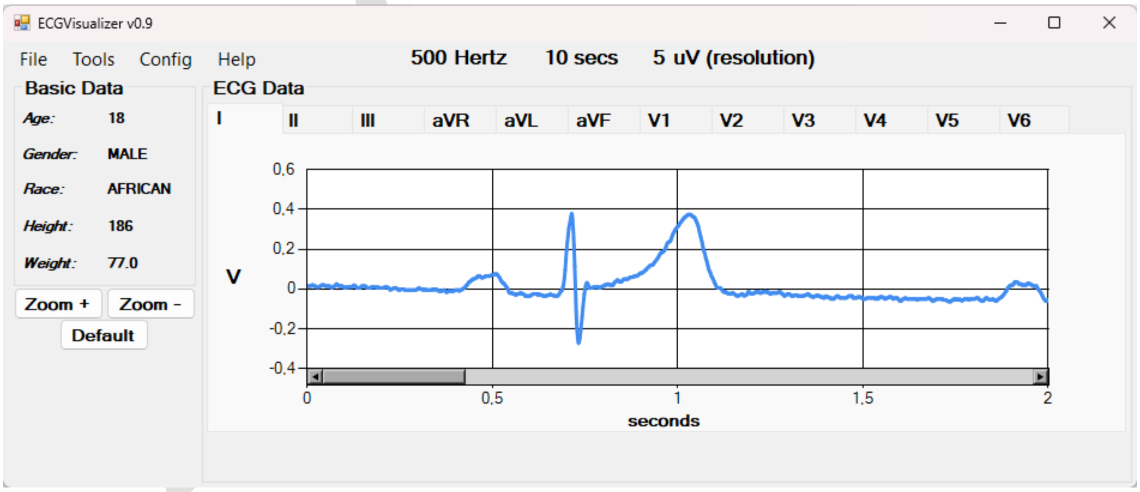
5. USING ECG VISUALIZER

This software tool allows the user to process the signal in an automatic or a manual way.

First, one the application has launched, user can open an XML file using the option "*File*" → "*Load ECG Data*":

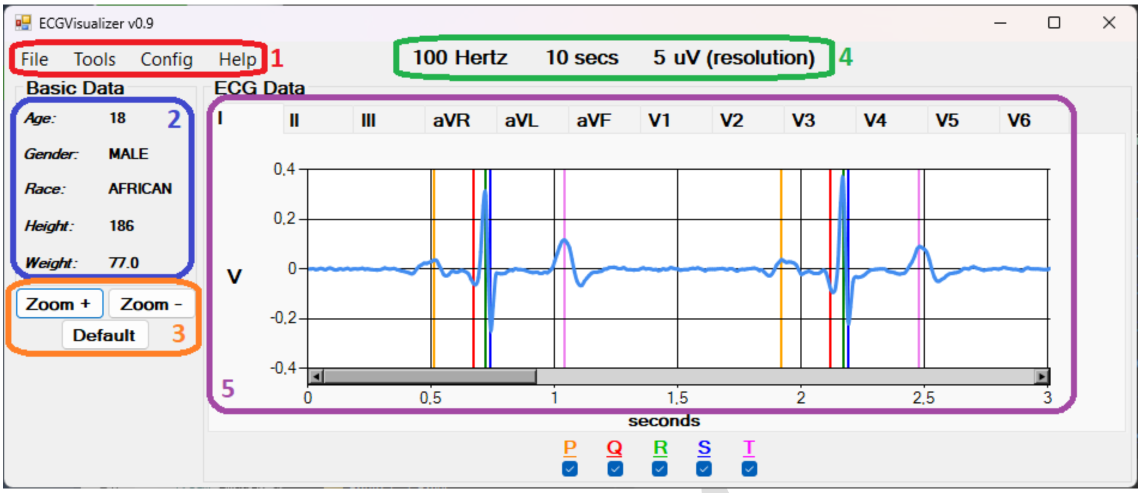


The 12-leeds ECG signal will be loaded and the application will look like this:



The basic patient information will be placed in the left column, the basic signal information in the upper part of the application, and the ECG data will be represented in the main part of the application.

A summary of the parts that make up the application is detailed below:

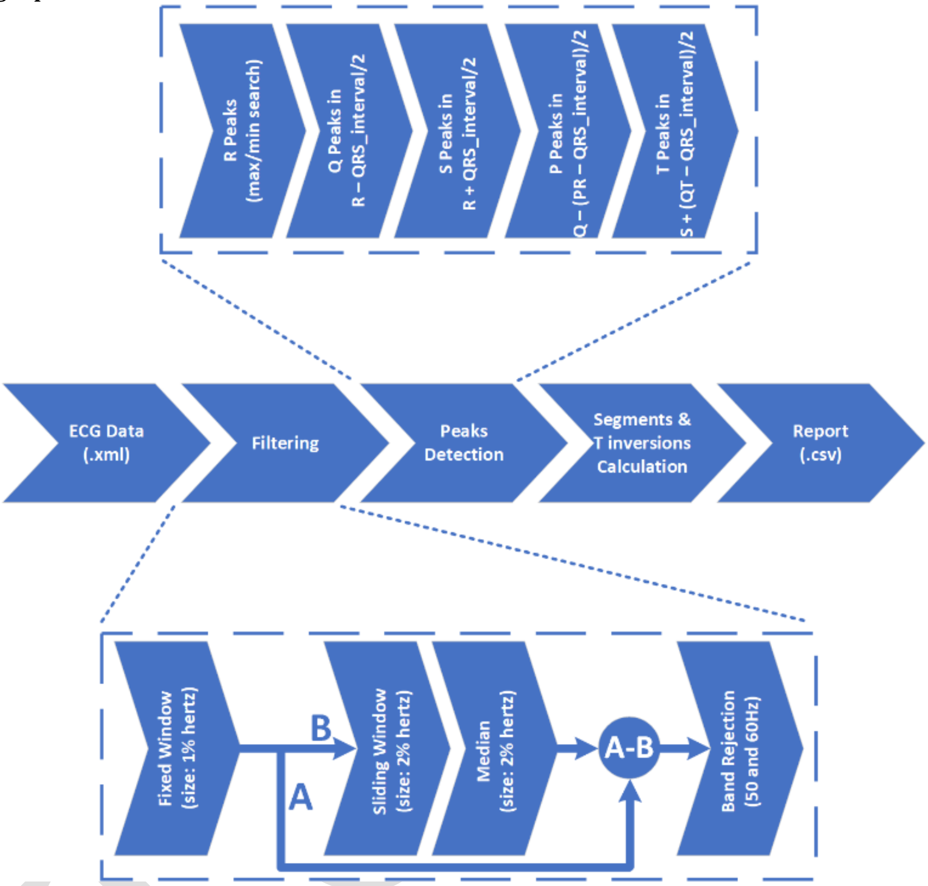


1. Section 1 (red): Toolsbar. This sections contains several options that allows the user loading ECG files, filtering ECGT signal, selecting the features extracted and configuring the report generated. All the options are described in the User Manual.
2. Section 2 (blue): Basic patient information. Here, the baseline information obtained from the ECG file is shown. This information may be selected to be included in the final report.
3. Section 3 (orange): Visualization tools. These tools allows the user to increase or decrease zoom. In the case the user want to return to the default zoom, he/she can clic on "Default".
4. Section 4 (green): Signal information. This is an informative section, where the main charactreristics of the loaded ECG signal are shown: Hertzs, number of seconds and resolution of the signal. Hertzs may vary when applying fixed-window average filters.
5. Section 5 (purple): ECG signal visualization. The 12-lead ECG signal is represented here. User may select which lead to visualize and move though it using the scrolls. The results of the filtering and peaks detection process are represented here too.

Once the ECG data is loaded, the user can perform the automatic or the manual processing method. Next, both modes will be explained.

5.1. AUTOMATIC PROCESSING

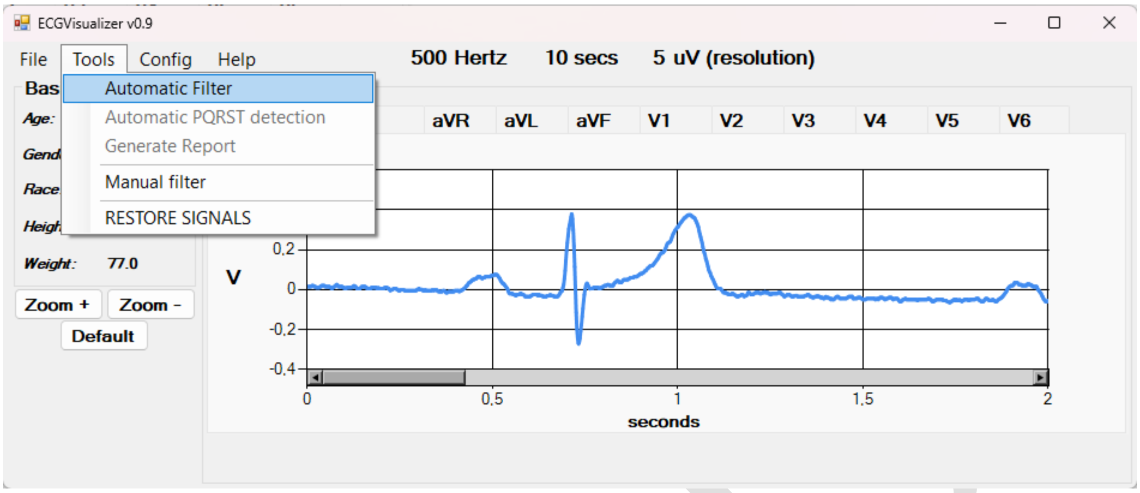
The full processing chain for the automatic mode is detailed in the next graph:



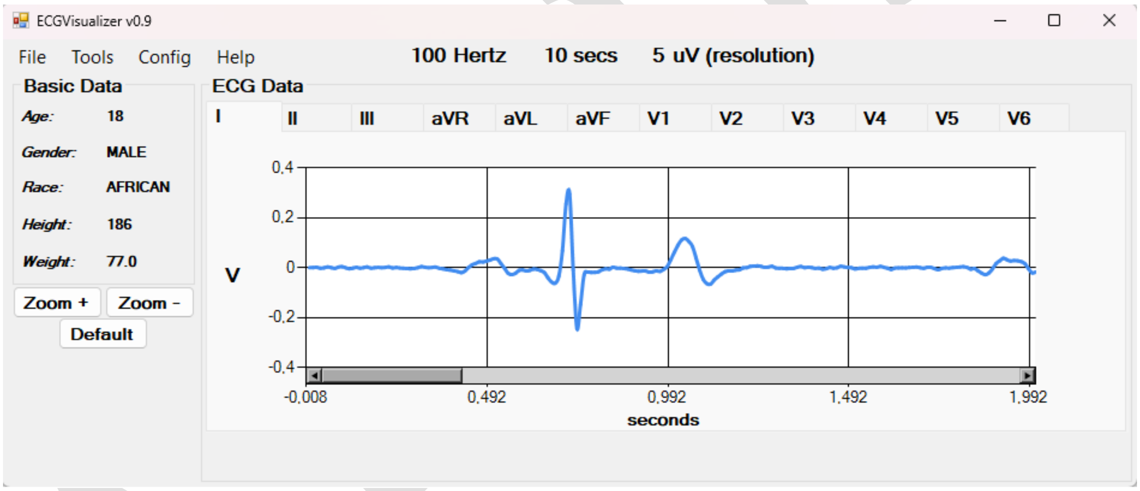
The automatic signal filtering process is explained below:

1. Fixed window average filter (mean filter or smoothing filter) with a window width of 1% of the sampling rate width. This filter removes the digital noise from the sampling and, as a side effect, reduces the sampling rate to 100 Hertz.
2. Sliding window average filter (or moving average filter) with a window width of 2% of the sampling rate width. This filter removes the high-frequency and low-frequency ripples.
3. Sliding window median filter (or moving median filter) with a window width of 2% of the sampling rate width. This filter flattens deeply the signal peaks and reduce the noise. After this step, the signal seems distorted, mainly keeping the information concerning the offset of the original signal against the reference voltage.
4. Signal obtained after previous step is subtracted from signal obtained after first filter. The resulting signal has no voltage offset with sharper peaks.
5. Band rejection filter (or band-stop filter) for 50 and 60 hertz. This filter eliminates the persistent noise caused by the electrocardiograph mains connection.

This automatic filtering can be executed by accessing the menu "*Tools*" → "*Automatic Filter*":



After this filtering, the resulting signal looks like this:



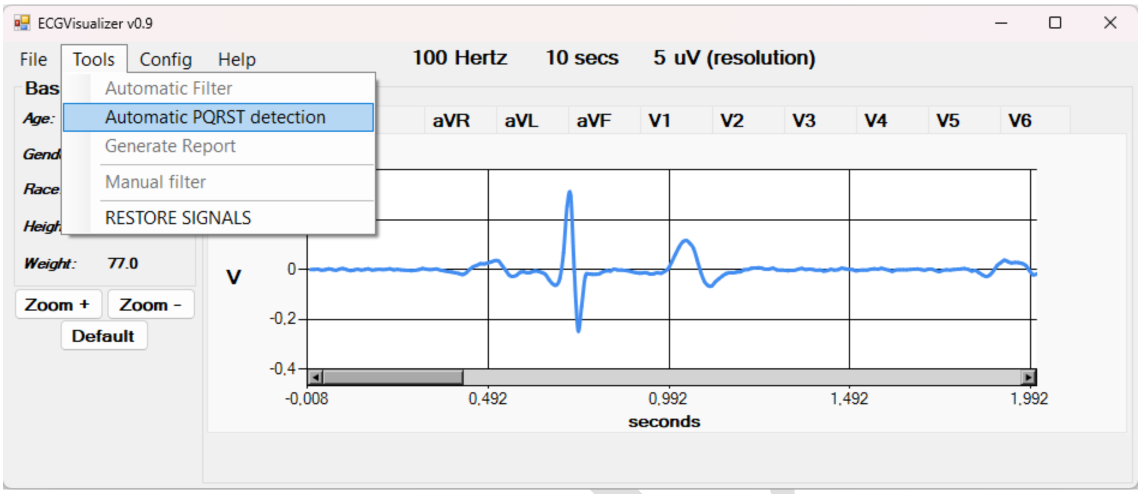
After it, the peaks detection process is performed by the same tool. As commented before, the tool allows the user to select the target user between a common person, an athlete or a custom class determined by the user; but automatically, it uses the "*athlete*" template.

The peaks detection process is described below:

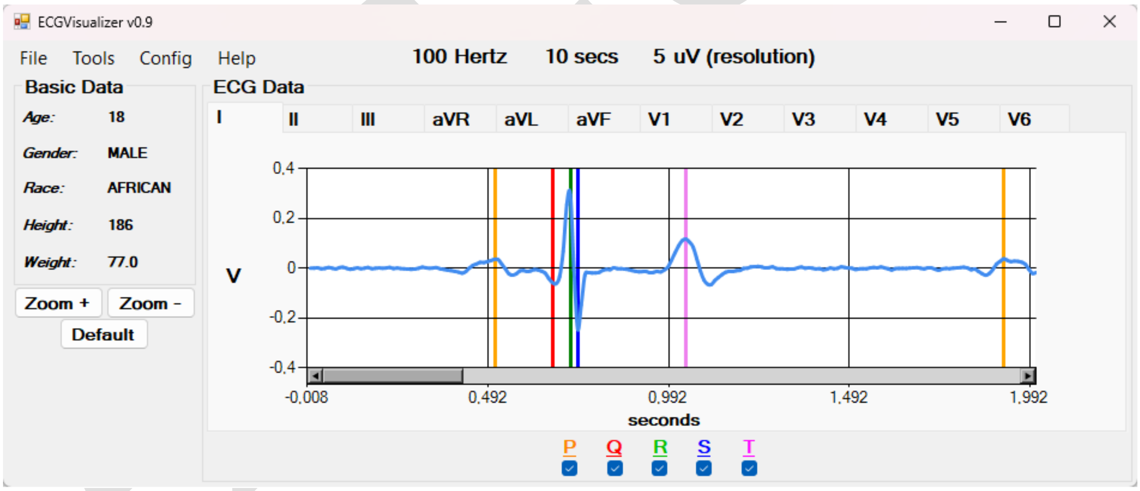
1. R peaks: the first value is searched using a local maximum search.
2. Q peaks: starting from the R peaks location, the search window is established by the QRS maximum and minimum intervals configured according to the type of user.
3. S peaks: they are detected following the same procedure as that used for the Q peaks, but in reverse.
4. P peaks: starting from the Q peaks location, the search window is established by the PQ maximum and minimum intervals configured according to the type of user.
5. T peaks: a similar procedure is performed as for P peaks but using the QT interval configured for the search window. The only aspect to take

into account is that we cannot consider that the polarity of the T peak is the same as that of the corresponding P and R peak. This aspect must be detected too.

This peaks detection process may be executed by accessing the menu "*Tools*" → "*Automatic PQRST detection*":

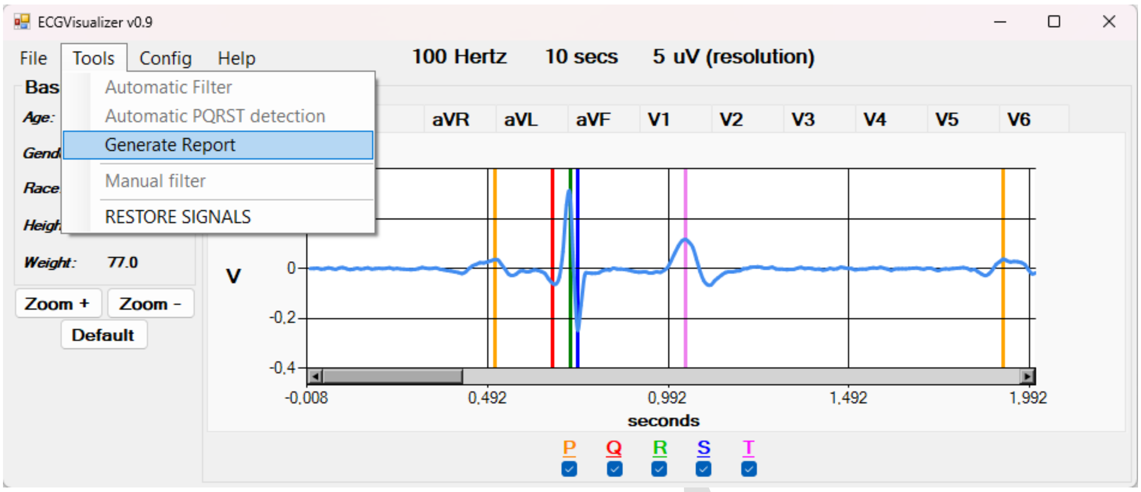


The result is shown next:



As can be observed, each peak type y represented with a different colour. User can hide some peak types by clicking on the checkbox shown below the ECG signal.

Finally, for the automatic report generation, the user should execute the menu "*Tools*" → "*Generate Report*", as shown next:



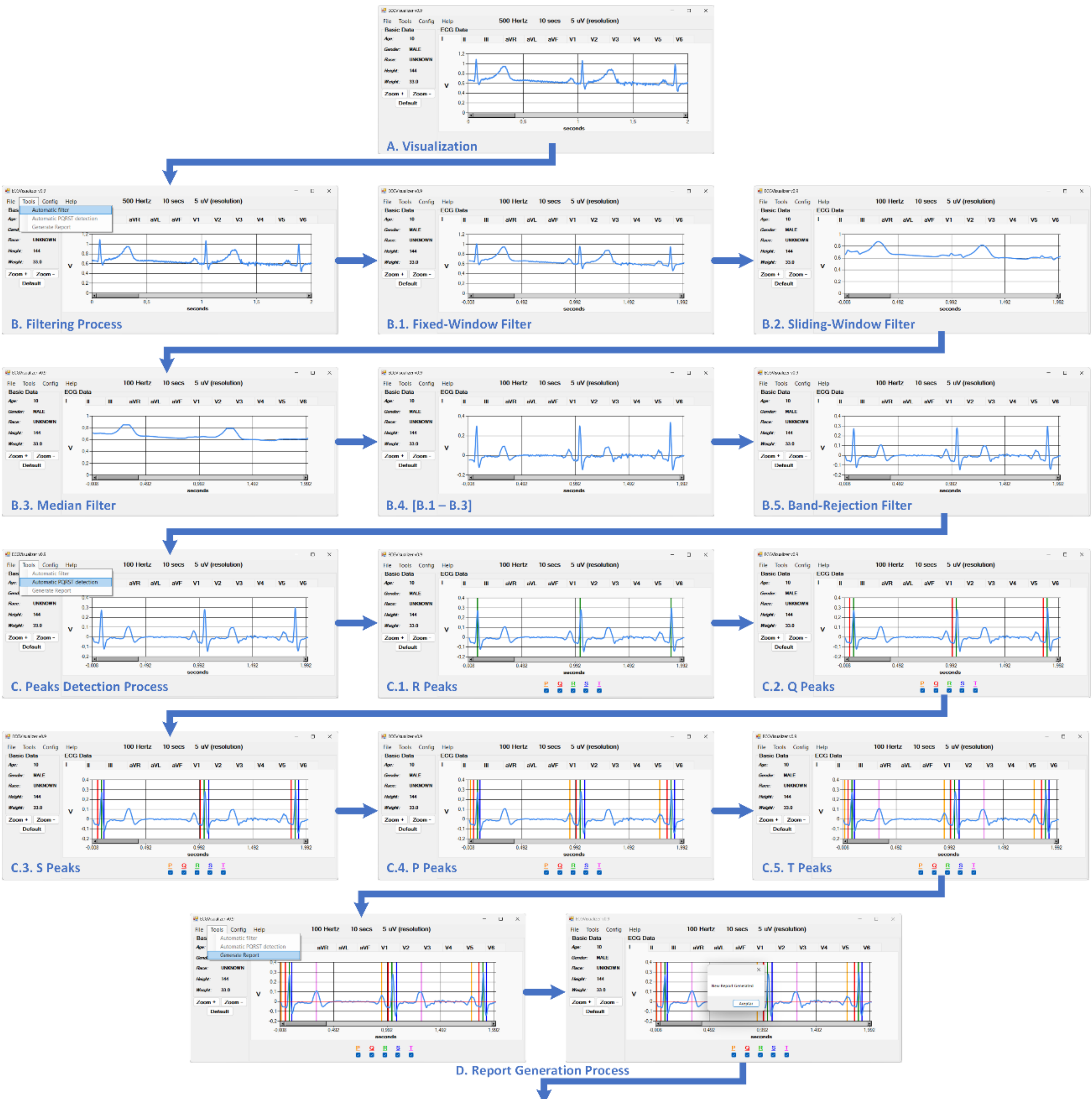
The tool will show a popup window indicating that the report has been created. It is generated in the same location as the .exe program with the name "*report.csv*".

If there is a previously generated report, the tool will append the information obtained for this patient as a new row in the same report.

The result of the automatic report generation is shown next:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	ID	Age	Race	Height	Weight	RR interval	QRS interval	QT interval	QT_c interva	T inv I	T inv II	T inv III	T inv aVR	T inv aVL	T inv aVF	T inv V1	T inv V2	T inv V3	T inv V4	T inv V5	T inv V6
2	example1	18	AFRICAN	186	77	1234,28571	82,8571429	360	300,782903	0	0	0	0	1	0	0	0	0	0	0	0

The full application usage diagram is presented next, summarizing the full automatic process described previously.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	Age	Gender	Race	Height	Weight	PQ interval	RR interval	QRS interval	QT interval	QT_c interval	T inv I	T inv II	T inv III	T inv aVR	T inv aVL	T inv aVF	T inv V1	T inv V2	T inv V3	T inv V4	T inv V5	T inv V6
2	10	MALE	UNKNOWN	144	33	74,6153846	72	72,3076923	291,538462	331,215425	0	0	0	0	0	0	0	0	0	0	0	0
3																						

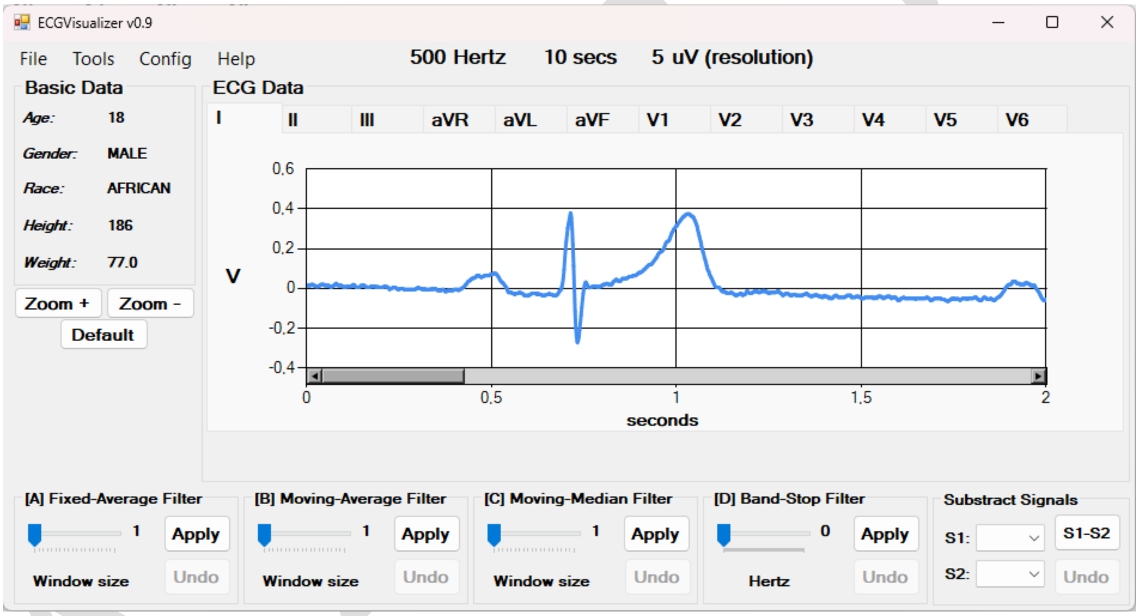
5.2. MANUAL PROCESSING

This section will provide information about the options available to customize the signal processing process.

The ECG loading option is the same indicated previously.

Once the ECG information is loaded, the first step is the filtering process. In this case, this tool allows you to select which filters you want to apply, with which window and in what order.

To access the manual filter menu, click on "*Tools*" → "*Manual filter*" and the application will be modified to look like the following:



As can be seen in the image, each filter appears in a separate box, allowing the user to set the desired window width using a scollbar, and apply it when appropriate.

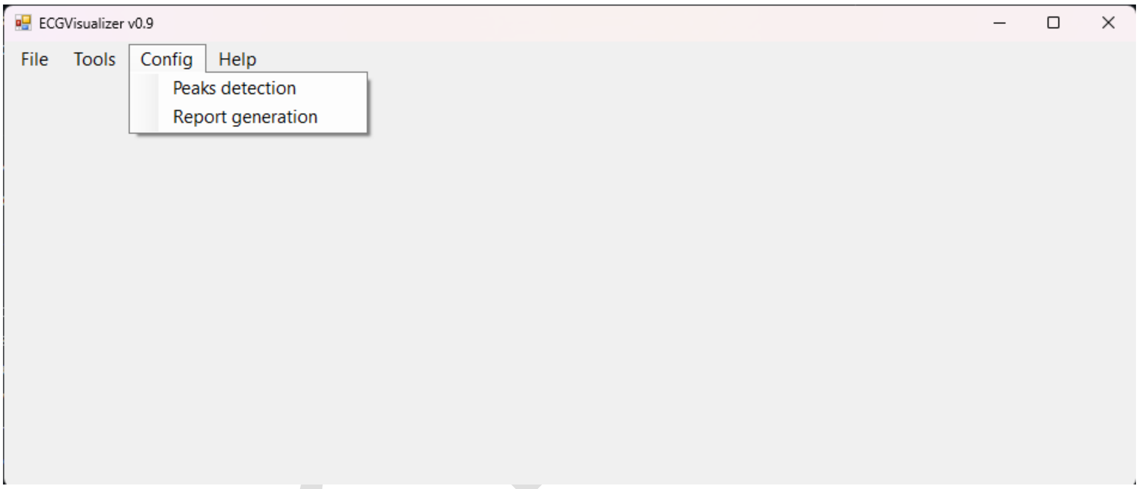
In addition, the state of the signal before the application of each filter is saved, which allows you to undo the changes of the last modification by means of the "*Undo*" option of each filter.

Finally, a box is included that allows the subtraction of signals from some of the previous filters. To do this, each signal is selected with the identifier A (result of the average filter with fixed window), B (result of the average filter with sliding window), C (result of the median filter with sliding window), D (result of the band-reject filter) or RAW (unfiltered original signal).

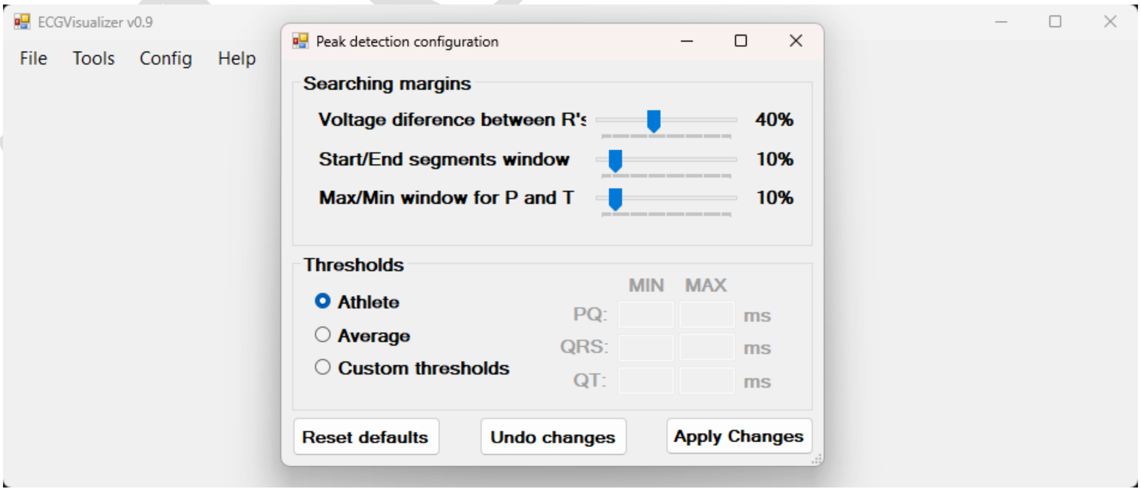
In all cases, once the "*Apply*" button is clicked, the result will be displayed immediately in the central area of the application.

After the filtering process, the user can carry out peak detection using the same menu explained in the automatic processing section. The difference is that, previously, the user can configure the maximum and minimum value of the characteristic segments of the patient whose ECG is being processed.

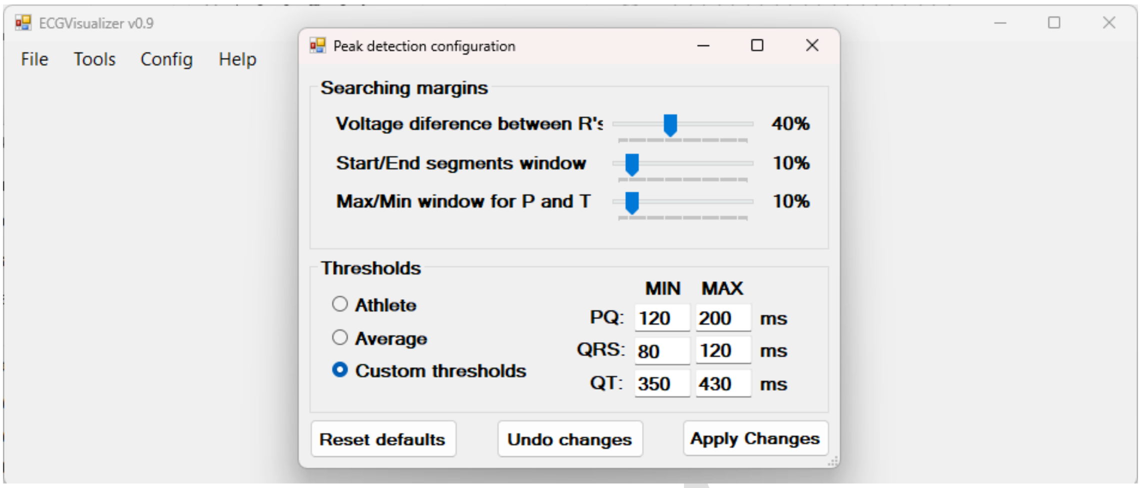
To do this, the user must access the menu "*Config*" → "*Peaks detection*":



A pop-up menu will then appear allowing the user to select one of the standard profiles (average patient or athlete):



…or manually set the values of the characteristic segments:



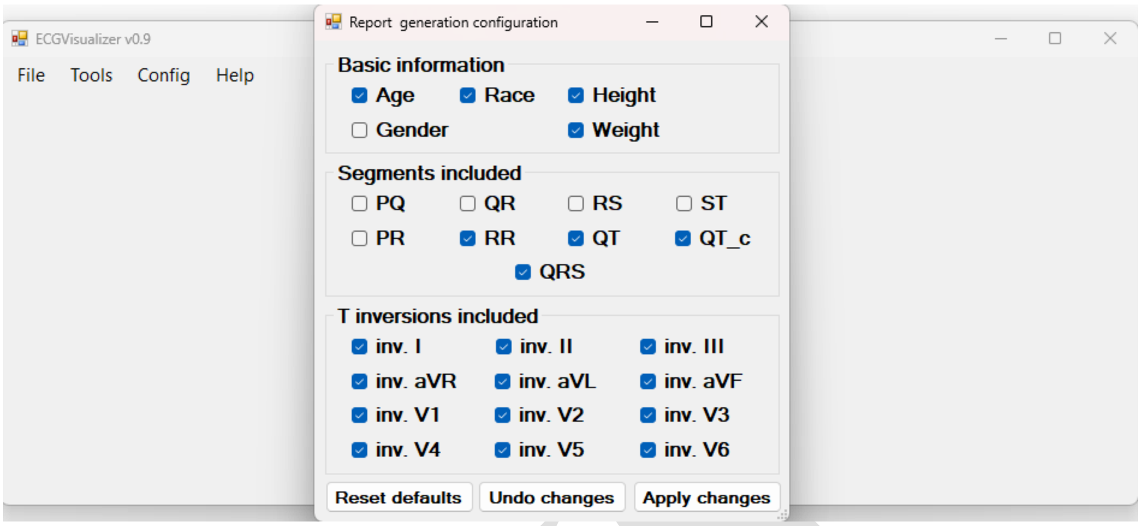
Other configurable parameters necessary for automatic peak detection are included in this same menu. By default they have already established values that, experimentally, have been verified to work correctly for patients of various profiles.

However, they can be varied by the user if the ECG signal used is very noisy or has a different reference voltage. These options are: the voltage difference in R peaks (variation that the signal can have between two R peaks, necessary for the automatic search of these peaks once the first one is detected); start/end of the segment window (it is basically an additional percentage of noise when detecting each peak within its established window, including an additional percentage variation for this search window); and the max/min window for the P and T peaks (set parameter that modifies the width of the window where to search for the local maximum or minimum to determine the exact point of the P and T peaks).

Once the user configures these parameters, you can proceed with the automatic search for PQRST peaks using the menu "*Tools*" → "*Automatic PQRST detection*".

With the signal already filtered and with the peaks detected, the last step is the generation of the report. At this point, the manual mode also allows you to choose which features are going to be extracted from the signal and included in the final report.

To do this, the user must access the menu "*Config*" → "*Report generation*". A new popup window will appear:



In this window, the user can select between three large blocks of characteristics.

The first one is the basic information of the patient. This information does not need to be computed, but has been initially extracted from the loaded XML and has been visible on the left side of the application from the start. The user must decide what to include of these parameters.

The second block refers to the calculated signal segments. By default, the most characteristic segments with RR (inverse of the heart beats), QT, corrected QT and QRS.

The calculation of the values of these segments is carried out with the second derivation (which, according to cardiologists, is the most used to carry out the measurements). For each pulse pattern of this derivation, the times are measured and the average of each segment among all the patterns of said derivation is provided.

Regarding the corrected QT, it is important to indicate that it is a manipulation of the original QT segment from which the dependence on heart rate is eliminated. This value is widely used and known among cardiologists.

Finally, the third block is formed by the inversions of the T waves of each of the leads. By default, all investments are selected, but the user can delete the ones he doesn't need.

The calculation of these inversions is made by comparing the polarity of each T peak with its corresponding R peak. To eliminate errors caused by display and filtering, the T wave of a lead is determined to be inverted if there are more patterns whose T is inverted than those that are not (This prevents erroneous point inversion).

Finally, for the automatic report generation, the user should execute the menu "*Tools*" → "*Generate Report*", as explained in the automatic process.

6. LOOKING FOR HELP

This tool has been developed by a small team of researchers from the University of Seville with the support of the medical manager of the professional football team RCD Mallorca SAD.

This tool is in continuous development and incorporating, day by day, new functionalities and compatibility with more devices. Therefore, we are aware that the tool may contain errors that will eventually be resolved.

In the event that the user detects a specific error, do not hesitate to contact **Professor Manuel Domínguez-Morales** through the email address ***mjdominguez@us.es***.

If what the user needs is more information regarding certain utilities or tool menus, they can access the "*Help*" → "*Information*" option of the software tool. There you will find information about supported devices, the automatic filtering process, patient profiles, and automatic PQRST peak detection.