First Pass Annotation Parameters:

First Pass Annotation Algorithm

First pass annotation uses a heuristic algorithm to find Q_{on}, Q_{off}, and T_{off} for each QRST complex in the VM lead. The VM lead is used for first pass annotation because it is always positive and the QRS magnitude tends to be larger than the T wave magnitude which helps simplify calculations. First pass annotation is controlled with the following parameters in `Annoparams.m`:

- `autoMF`
- `autoMF_thresh`
- `MF_width`
- `QRwidth`
- `RSwidth`
- `STstart`
- `STend`
- `Tendstr`

First pass annotation is controlled by the `autoMFannotate.m` subroutine which uses these parameters, the locations of the dominant R peaks in the VM lead, and any pacing spikes, in order to set the search windows for the beginning and ending of the QRS complex and T wave. If `autoMF = 1` the QRS search algorithm dynamically estimates the QRS search window by estimating the the width of the QRS peak in the VM lead after median filtering with a filter width of `MF_width`. Using `autoMF = 1` is usually better than manually setting a static QRS search window using `QRwidth` and `RSwidth` because all beats are not necessarily the same width, and a fixed search window may not work for all beats. The search window is set for each individual peak to twice the the width of the region of points greater than the percentage `autoMF_thresh` of the height of the median-filtered dominant R-wave peak. If `autoMF = 0`, the provided, and static, values of `QRwidth` and `RSwidth` are used to set the QRS search window for all peaks.

Once the QRS search window is established, for each QRS complex, the start (Q_{on}) and end (Q_{off}) are determined as follows. First, the algorithm determines if there is an additional peak in the VM lead before the dominant R wave peak within a short distance (i.e. a Q wave). Two methods are then used to determine the start of the peak. Method A finds the maximum slope and walks out until it finds a point where the absolute value of the derivative is 2% of the maximum slope (or the smallest value found if not 2%). Method B looks for the first local minimum and labels this as the fiducial point. The point closest to dominant R-wave from methods A and B is chosen as the fiducial point.

After Q_{on} and Q_{off} are located, a blanking window equal to `STstart` ms is set after the location of Q_{off} during which the T wave cannot be detected to avoid issues if Q_{off} is not detected correctly. At the end of this `STstart` window, the T wave search window starts and is extended by `STend` % of the mean RR interval. `STend` is set as a % of the mean RR interval rather than an absolute value in ms to minimize the need to change parameter values as QT interval is related to RR interval. The location of T_{off} is then detected by the method specified in `Tendstr`.

If `Tendstr` is `'baseline'` or `'tangent'`, the second half of the T-wave is fit to $A\exp\{(t/\sigma)^B\}$. The intersection of the function, or the tangent to the maximum negative slope with the baseline, is then calculated. If `Tendstr` is `'energy'`, the T-wave offset is chosen by a method based on the derivative of the signal (see reference [1]).

First Pass Annotation Figure

First pass annotation is summarized in the following figure:

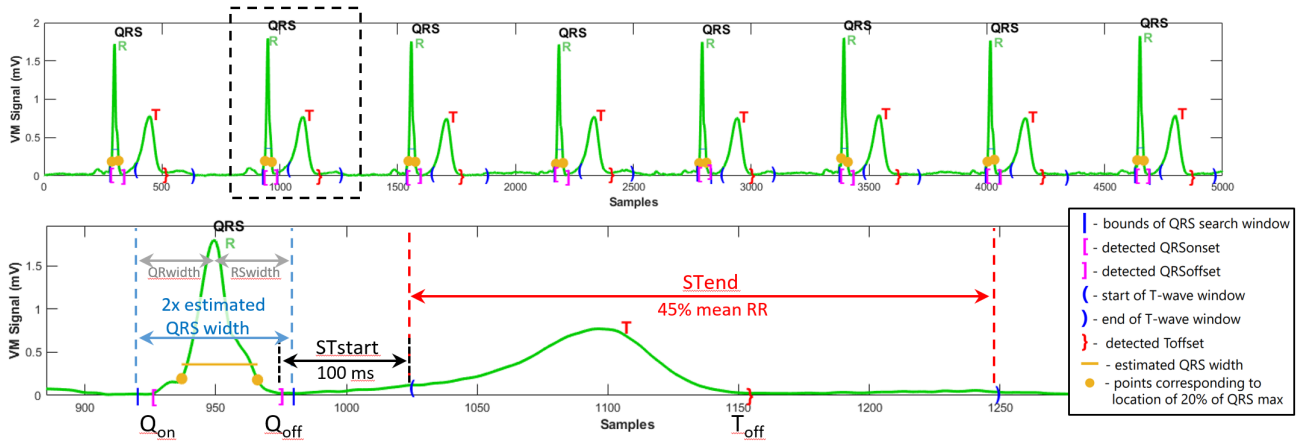

Figure 1: First pass annotation and search windows. The upper panel shows annotation search windows/detected points for the entire VM lead. The bottom panel shows a zoomed in view of the second beat (dashed box). If `auto_mf = 1`, the values of `QRwidth` and `RSwidth` (grey) are disabled and the QRS search window is dynamically estimated for each beat as twice the width of the median filtered QRS complex at `autoMF_thresh` % of the R peak voltage (nomimally 20% - yellow dots/line) for that beat centered on the R peak. If `auto_mf = 0` the values of `QRwidth` and `RSwidth` are used to set the width of the QRS search window before and after the R peak, respectively. The blue | symbols denote the beginning and end of the QRS search window and can help determine if the QRS detection window is too wide/narrow. Within the bounds of the QRS search window, Q_{on} and Q_{off} are detected as noted in the text with locations noted as [and], respectively. Once Q_{off} is detected, a blanking period set by `STstart` (nominally 100 ms) extends forward from the location of Q_{off}, marking the start of the T wave search window ((). The T wave search window extends forward by `STend` % of the mean RR interval (nominally 45%) and ends at the) symbol. Within the T wave search window bounds, the location of T_{off} is marked with a }.

Common Annotation Parameter Problems

The nominal value of `autoMF_thresh = 20`. Consider what can happen if `autoMF_thresh` is set too low:

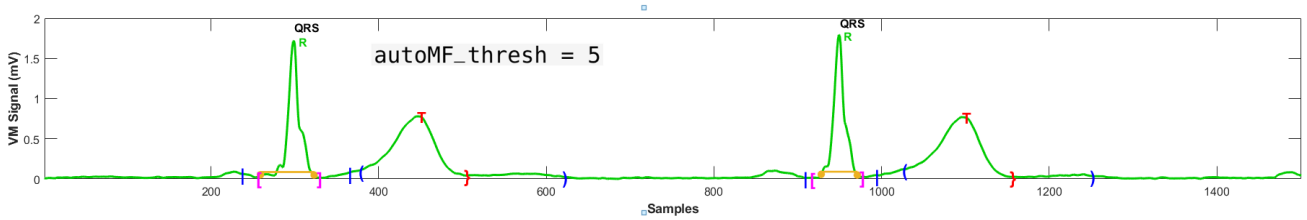

Figure 2: `autoMF_thresh = 5` is set too low. See text for details.

As shown in **Figure 2**, if `autoMF_thresh = 5` is set too low, more than the true QRS complex may be detected as part of the QRS complex (see orange circles and line), resulting in the estimated QRS width and the QRS search window (|) being too wide. This prevents accurate annotation of Q_{on} ([) and Q_{off} (]), but also can interfere with the T wave search window ((to)) and locating T_{off} (}) because the onset of the T wave search window starts `STstart` ms after the location of Q_{off}.

As shown in **Figure 3**, if `autoMF_thresh` is set too high, the QRS search window is likely to be too narrow:

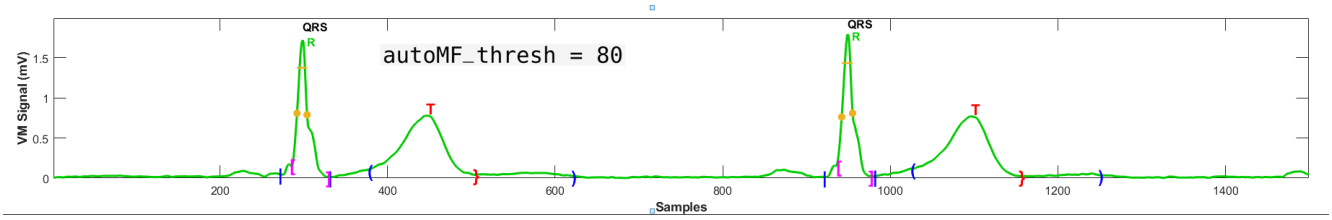

Figure 3: `autoMF_thresh = 80` is set too high. Se text for details.

Note that in this example, Q_{on} ((]) is annotated later than the true QRS onset because the search window is not wide enough.

In cases where atypical QRST morphology is causing issues with first pass annotation, setting `autoMF = 0` in `Annoparams.m` or by unchecking the ☐ Auto Width checkbox, can allow manually setting the QRS search window by setting the values of `QRwidth` and `RSwidth`.

As shown in **Figure 4**, if `STend` is too short, the end of the T wave may not be found:

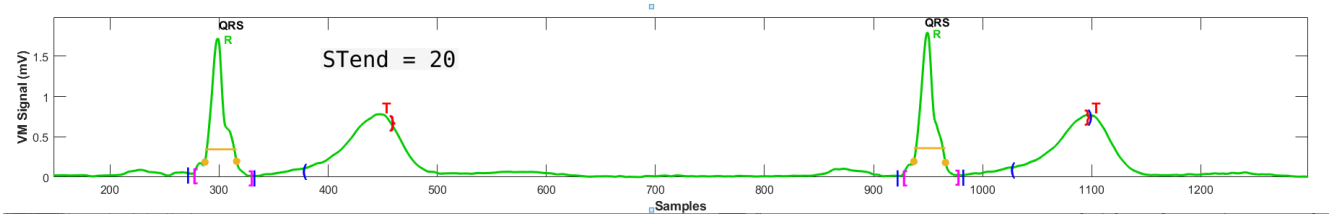

Figure 4: `STend = 20` is set too short. Se text for details.

In this example, the end of the T wave search window ()) is too short to include the entire T wave, and the location of T_{off} (}) is therefore not accurate. If `STend` is longer than necessary this usually does not cause as many issues as if `STend` is too short, as long as the end of the T wave search window does not encroach on the start of the next PQRST complex.

1 References

[1] L. Johannesen, J. Vicente, M. Hosseini, and D. G. Strauss. Automated Algorithm for J-Tpeak and Tpeak-Tend Assessment of Drug-Induced Proarrhythmia Risk. *PLoS One*, 11(12):e0166925, 2016.