ECG Modeling for Simulation of Arrhythmias in Time-Varying Conditions: Default Parameter Values

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The default value for the ECG simulator parameters that are introduced in the manuscript are listed here. Parameters provided with ranges are uniformly distributed and are sampled either on a beat, episode, lead or record basis. The range sampling rules are indicated at the end of each table. Additionally, the probability of APB type, VPB type, and bigeminy over trigeminy (involving, respectively, $p_{\mathrm{APB}i}$, $p_{\mathrm{VPB}i}$ and p_{B}) is sampled at each transition of the Markov chain to the respective AT, VPB and BT states.

Atrial premature beats

Parameter	Value	Meaning
$\beta_{\mathrm{APB1,p}}$	$[0.55, 0.95]$	RR interval prematurity factor of APB with sinus node reset
$\beta_{\mathrm{APB2,p}}$	$[0.55, 0.95]$	RR interval prematurity factor of APB with delayed sinus node reset
$\beta_{\mathrm{APB2,f}}$	$[1.10, 1.35]$	RR interval compensatory pause factor of APB with delayed sinus node reset
$\beta_{\mathrm{APB3,p}}$	$[0.55, 0.95]$	RR interval prematurity factor of APB with compensatory pause
$\beta_{\mathrm{APB4,p}}$	$[0.55, 0.65]$	RR interval prematurity factor of interpolated APB
p_{APB1}	0.3	Probability of APB with sinus node reset
p_{APB2}	0.3	Probability of APB with delayed sinus node reset
p_{APB3}	0.3	Probability of APB with compensatory pause
p_{APB4}	0.1	Probability of interpolated APB

These parameters with ranges are sampled on a beat basis.

Atrial tachycardia

Parameter	Value	Meaning
p_{APB}	0.95	Probability of APBs in AT episode duration PMF
p_{AC}	0.040	Probability of atrial couplets in AT episode duration PMF
b_{AT}	1.00	Exponential decay in AT episode duration PMF for $l \geq 3$
$\beta_{\mathrm{AT,p}}$	$[0.55, 0.95]$	RR interval prematurity factor of AT episode, sampled only at AT episode onset
$\beta_{\mathrm{AT,f}}$	$[0.70, 1.50]$	RR interval compensatory pause factor for AT episode, sampled only at AT episode end
β_{AT}	$[0.5, 0.91]$	RR interval shortening factor for RR intervals inside the AT episode, sampled only at AT episode onset
Δd_{RR}	$[-50, 50]$ ms	RR interval variability factor for RR intervals inside the AT episode

These parameters with ranges are sampled on a episode basis, except Δd_{RR} which is sampled for each beat of the AT episode.

Ventricular premature beats

Parameter	Value	Meaning
$\beta_{\mathrm{VPB1,p}}$	$[0.55, 0.9]$	RR interval prematurity factor of VPB with full compensatory pause
$\beta_{\mathrm{VPB2,p}}$	$[0.55, 0.9]$	RR interval prematurity factor of VPB with noncompensatory pause
$\beta_{\mathrm{VPB3,p}}$	$[0.55, 0.65]$	RR interval prematurity factor of interpolated VPB
p_{VPB1}	0.47	Probability of VPB with full compensatory pause
p_{VPB2}	0.47	Probability of VPB with noncompensatory pause
p_{VPB3}	0.06	Probability of interpolated VPB

These parameters with ranges are sampled on a beat basis.

Bigeminy and trigeminy

Parameter	Value	Meaning
p_{B}	0.72	Probability of bigeminy over trigeminy
a_{BT}	0.84	Exponential amplitude factor in BT episode duration PMF
$\beta_{\mathrm{BT,p}}$	$[0.55, 0.9]$	RR interval prematurity factor of ventricular beat during bigeminy or trigeminy
$\beta_{\mathrm{BT,f}}$	$[1.1, 1.3]$	RR interval compensatory pause factor of ventricular beat during bigeminy or trigeminy

These parameters with ranges are sampled on a beat basis.

Atrial fibrillation

Parameter	Value	Meaning
b_{AF}	0.012	Exponential decay in AF episode duration PMF

Muscular noise

Parameter	Value	Meaning
ν	$[0.99, 0.9995]$	Filter parameter which models the standard deviation of the muscular noise $w(n)$
σ_w^2	10 μV	Variance of variation of the simulated muscular noise $x_{\sigma_w}(n)$
$m_{\sigma_w}(n)$	20 μV	The muscular noise intensity
$\sigma_{w,min}$	0 μV	Minimum value of the muscolar noise standard deviation $w(n)$

The parameter ν is sampled on a record basis.

Motion artifacts

Parameter	Value	Meaning
N	2000 ms	Length of the impulse response $h(n)$
α_1	$[0.7, 99]$	Coefficient of the exponentially increasing part of the impulse response
α_2	$[0.7, 99]$	Coefficient of the exponentially decreasing part of the impulse response
K	$[500, 1500]$ ms	Impulse response turning point

These parameters with ranges are sampled on a lead basis.

Respiratory cycle

Parameter	Value	Meaning
γ_{in} (γ_{ex})	3	Inspiration/expiration steepness during the respiratory cycle
δ_{in}	$[1.8, 2.2]$ s	Inspiration approximate duration
δ_{ex}	$[6.3, 7.7]$ s	Expiration approximate duration
$\alpha_{o,p}$	$[0.9, 1.1]$	Amplitude of the template respiratory cycle
T_r	10 s	Template respiratory cycle duration
ξ_o	5 degrees	Angular signal $\varphi(t)$ maximum variation

The δ_{in} and δ_{ex} parameters are sampled for each respiratory cycle. The parameter $\alpha_{o,p}$ is sampled for each respiratory cycle, for each lead.

Parameters from the previous version of the simulator

For the sake of completion the parameters of the various simulator model components inherited from the previous simulator version are reported here. For refence on parameter definitions please see doi.org/10.1088/1361-6579/aa9153. The parameters about P wave and QRST complex morphology generation have been updated to improve signal realism. The rest of model parameters are left unchanged.

P wave Hermite function coefficient ranges

	Lead		
Parameter	X	Y	Z
$\sigma_{\mathrm{P},0}$	$[0.8, 0.9]$	$[0.8, 0.9]$	$[0.5, 0.9]$
$\sigma_{\mathrm{P},1}$	$[0.5, 0.9]$	$[0.5, 0.9]$	$[0.7, 0.9]$
$\sigma_{\mathrm{P},2}$	$[0.5, 0.9]$	$[0.5, 0.9]$	$[0.6, 0.9]$
$w_{l,0}$	$[0.04, 0.09]$	$[0.05, 0.125]$	$[-0.02, 0.02]$
$w_{l,1}$	$[-0.02, 0.02]$	$[-0.03, 0.03]$	$[-0.02, -0.05]$
$w_{l,2}$	$[0, 0.02]$	$[0, 0.03]$	$[-0.02, 0]$

These parameters with ranges are sampled on a record basis twice: first for the sinus P wave and then for the non-sinus P wave.

QRST complex Gaussian function coefficient ranges

	Parameter		
k	$\alpha_{\mathrm{X},k}$	$\alpha_{\mathrm{Y},k}$	$\alpha_{\mathrm{Z},k}$
1	$-0.4A_x - 0.05$	0	$-0.4A_z - 0.05$
2	$1.5A_x + 0.4$	$0.7A_y + 0.1$	0
3	0	$-0.3A_y - 0.05$	$A_z + 0.1$
4	T_x	T_y	T_z
5	$2T_x$	$2T_y$	$2T_z$
6	$3T_x$	$3T_y$	$3T_z$

Parameter	Range
A_{QRS}	$[0, 1.25]$
A_x	$[A_{\mathrm{QRS}} - 01, A_{\mathrm{QRS}} + 0.1]$
A_y	$[A_{\mathrm{QRS}} - 01, A_{\mathrm{QRS}} + 0.1]$

A_z	$[A_{\text{QRS}} - 01, A_{\text{QRS}} + 0.1]$		
T_x	$[0.06, 0.12]$ if $A_{\text{QRS}} \leq 0.5$, $[0.02, 0.08]$ if $A_{\text{QRS}} > 0.5$		
T_y	$[0.026, 0.05]$ if $A_{\text{QRS}} \leq 0.5$, $[0.01, 0.034]$ if $A_{\text{QRS}} > 0.5$		
T_z	$[-0.052, 0.1]$ if $A_{\text{QRS}} \leq 0.5$, $[-0.02, 0.068]$ if $A_{\text{QRS}} > 0.5$		

	Parameter		
k	$\sigma_{\text{X},k}$	$\sigma_{\text{Y},k}$	$\sigma_{\text{Z},k}$
1	$[0.05, 0.08]$	$[0.05, 0.08]$	$[0.05, 0.08]$
2	$[0.05, 0.08]$	$[0.05, 0.08]$	$[0.05, 0.08]$
3	$[0.05, 0.08]$	$[0.05, 0.08]$	$[0.05, 0.08]$
4	T_w	T_w	T_w
5	$T_w/2$	$T_w/2$	$T_w/2$
6	$T_w/4$	$T_w/4$	$T_w/4$

Parameter	Range
T_w	$[0.5, 0.7]$

	Parameter		
k	$\mu_{\text{X},k}$	$\mu_{\text{Y},k}$	$\mu_{\text{Z},k}$
1	-0.1	-0.1	-0.1
2	0	0	0
3	0.1	0.1	0.1
4	1.1	1.1	1.1
5	1.4	1.4	1.4
6	1.6	1.6	1.6

These parameters with ranges are sampled on a record basis.

f–waves morphology

Parameter	Value	Meaning
I	3	Harmonics number
ΔF	0.25 Hz	Maximum frequency deviation
F_m	0.2 Hz	Modulation frequency
F_a	0.2 Hz	Amplitude modulation frequency
a_{X}	$[15, 45]$ μV	Sawtooth amplitude in lead X

a_{Y}	$[15, 40]$ μV	Sawtooth amplitude in lead Y
a_{Z}	$[25, 70]$ μV	Sawtooth amplitude in lead Z
Δa_l	$a_l/3$	Modulation amplitude
$F_{l,0}$	$[3, 7]$ Hz	Atrial fibrillation frequency
$\sigma^2_{l,s}$	$a_l/2$ Hz	White noise variance

These parameters with ranges are sampled on a record basis.

Ventricular activity dyring atrial fibrillation

Parameter	Value	Meaning
ϵ	0.6	Probability of slower conduction pathway
τ_1	$0.25s$	Shorter refractory period
τ_p	$0.1s$	Maximal refractory period prolongation
d_{RP}	$0.2s$	Difference between refractory periods

Sinus rhythm generation

Parameter	Value	Meaning
$\bar{m}_{\mathrm{HR}}$	$[50, 90]$ BPM	Mean heart rate
σ_{HR}	$[0.5, 3]$ BPM	Heart rate standard deviation
F_1	0.1 Hz	Mayer wave frequency
F_2	$[0.2, 05]$ Hz	Respiratory rate
$\sigma_{\mathrm{V},1}$	0.01 Hz	Standard deviation of F_1
$\sigma_{\mathrm{V},2}$	0.01 Hz	Standard deviation of F_2
P_1/P_2	$[0.5, 2]$	Low–frequency to high–frequency ratio

These parameters with ranges are sampled on a record basis.