2. WHO, The top 10 causes of death, Jan 2017
21. WHO, Cardiovascular diseases (CVDs), Oct 2015
43. M. Elgendi, M. Jonkman, F. De Boer, Recognition of T waves in ECG signals, in IEEE Conference on Bioengineering (2009), pp. 1–2
56. TI, Ultra-low power comparison: MSP430 vs. microchip XLP tech brief (2009)
70. TI, MSP430FR2433 mixed-signal microcontroller (2015)
71. ATMEL, ATMEL 8-BIT Microcontroller with 4/8/16/32Kbytes in-system programmable flash (2015)
Index

A
Absolute value curve length transform (A-CLT), 44–46, 63
ACL core, 55–56
Adaptive filters, 16
American Heart Association (AHA), 28, 79
Applications, IoT healthcare
BP monitoring, 8–9
ECG monitoring, 8–9
glucose level sensing, 8
oxygen saturation monitoring, 9
Automated iterative multiplier ensembles (AIME), 60

B
Bayesian approach, 16
Big data, 10
Biomedical SoCs
architecture of, 21–22
16-bit CPU, 21
clock gating, 24
DSP algorithms, 21
duty cycling, 24–26
implantable applications, 23, 25
IoTs, 23–24
power and clock gating techniques, 23
power gating, 24
power reduction, 22–23
voltage scaling, 24
BLE technologies, 12
Blood glucose monitors, 1
Blood pressure (BP) monitoring, 9

C
CAN detection algorithms, 72–75
architectures
mean RR, 69
QTBI, 68–69
RMSSD, 69–70
SDRR, 70
QTBI-based methods, 62
Renyi entropy, 62
T-E technique, 61–62
time domain RR-based methods, 61
Cardiac autonomic neuropathy (CAN), 4, 21, 59
Cardiac autonomic reflex testing (CARTs), 59
Chip implementation, 75–77
Clock gating, 24, 33–34
Cloud computing, 10
Combined CLT and DWT-based ECG processor, 5
Communication networks, 10, 12
Compressor comparison, 56–57
Continuous monitoring, 12
Conventional CLT (C-CLT), 43–44
Core technologies
big data, 10
cloud computing, 10
communication networks, 10
grid computing, 10
IoT processors, 10
ultra-low power sensors, 9
wearable, 11
Curve length transform (CLT), 43–44
Custom finite state machine (FSM), 28
D
Data storage, 12
Delineation, 16
Diabetes Complications Research Institute (DiScRi), 72
Differentiation and adaptive thresholding, 42
Direct memory access (DMA), 21
Discrete Fourier transform, 15
Discrete wavelet transform (DWT), 27, 42
    baseline-wander ECG, 17–18
    clean ECG, 17–18
    50 Hz corrupted ECG, 17–18
    QRS detection and delineation, 17–19
    T and P wave delineation, 19–20
    trous algorithm, 16–17
    WT, 16
DSP algorithms, 21
Duty cycling, 24–26

E
ECG feature extraction, 34, 71–72
    die photo, 36, 38
    duty-cycled operation, 38
    energy per cycle, 35–36
    extracted $P_{on} - R, R - T_{peak}$, 34–35
    extracted QT intervals and heart rate, 34–35
    leakage power, 36
    power consumption, 35–36
    proposed system architecture
    flip-flop-based RAM, 63–64
    flow diagram of, 66–67
    latch-based RAM, 63–64
    proposed ACLT architecture, 64–65
    proposed T and P wave detector, 66, 68
    P-wave, 63
    QRS-complex, 63
    $QRS_{on}$ and $QRS_{off}$ detector, 66
    QT and RR intervals, 63
    SRAM-based memory, 63–64
    T-wave, 63
    published work comparison, 36–37
    system architecture
    baseline wonder, 28
    CLT buffer, 30
    CLT signal out, 31–32
    custom designed FSM, 28
    DWT-based T and P wave delineation, 31–32
    flow diagram of, 28–29
    motion artifacts, 28
    pipelined architecture, 30–31
    power-line interference, 28
    power reduction techniques, 33–34
    QRS detection, 30–32
    ECG processing
    analog front end, 13–14
    basic signal, 13–14
    biomedical SoCs
    architecture of, 21–22
    16-bit CPU, 21
    clock gating, 24
    DSP algorithms, 21
    duty cycling, 24–26
    implantable applications, 23, 25
    IoTs, 23–24
    power and clock gating techniques, 23
    power gating, 24
    power reduction, 22–23
    voltage scaling, 24
classifiers, 21
delineation, 16
discrete Fourier transform, 15
DWT
    baseline-wander ECG, 17–18
    clean ECG, 17–18
    50 Hz corrupted ECG, 17–18
    QRS detection and delineation, 17–19
    T and P wave delineation, 19–20
    trous algorithm, 16–17
    WT, 16
    Hilbert transform, 15
    P-wave, 14
    QRS complex, 14
    QRS detection techniques, 15
    spectrum, 14–15
time domain thresholding, 15
    T-wave, 14
    U-wave, 14
    wavelet transform, 15
Electrocardiogram (ECG), 1
    compression architectures, 42
    feature extraction (see ECG feature extraction)
    monitoring, 8–9
    node, 2
    processing (see ECG processing)
Energy consumption, 11–12
Energy dissipation, 1
ExG sensors, 1

F
Fan architecture, 42
Flip-flop-based RAM, 63–64

G
General-purpose micro-controllers, 41
Gibbs sampler, 16
Glucose level sensing, 8
Grid computing, 10

<table>
<thead>
<tr>
<th>H</th>
<th>Healthcare, IoT, see Internet of Things</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heart rate sensors, 1</td>
</tr>
<tr>
<td></td>
<td>Heart rate variability (HRV), 59–60</td>
</tr>
<tr>
<td></td>
<td>Hidden Markov models, 16</td>
</tr>
<tr>
<td></td>
<td>High voltage threshold (HVT), 75, 77</td>
</tr>
<tr>
<td></td>
<td>Hilbert transform, 15</td>
</tr>
<tr>
<td></td>
<td>Holter monitors, 39</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>I</th>
<th>Internet of Things (IoT), 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>applications</td>
</tr>
<tr>
<td></td>
<td>BP monitoring, 8–9</td>
</tr>
<tr>
<td></td>
<td>ECG monitoring, 8–9</td>
</tr>
<tr>
<td></td>
<td>glucose level sensing, 8</td>
</tr>
<tr>
<td></td>
<td>oxygen saturation monitoring, 9</td>
</tr>
<tr>
<td></td>
<td>challenges in, 11–12</td>
</tr>
<tr>
<td></td>
<td>core technologies</td>
</tr>
<tr>
<td></td>
<td>big data, 10</td>
</tr>
<tr>
<td></td>
<td>cloud computing, 10</td>
</tr>
<tr>
<td></td>
<td>communication networks, 10</td>
</tr>
<tr>
<td></td>
<td>grid computing, 10</td>
</tr>
<tr>
<td></td>
<td>IoT processors, 10</td>
</tr>
<tr>
<td></td>
<td>ultra-low power sensors, 9</td>
</tr>
<tr>
<td></td>
<td>wearable, 11</td>
</tr>
<tr>
<td></td>
<td>healthcare platform, 39–40</td>
</tr>
<tr>
<td></td>
<td>healthcare security, 11</td>
</tr>
<tr>
<td></td>
<td>processors, 10</td>
</tr>
<tr>
<td></td>
<td>trends for, 7–8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>L</th>
<th>Latch-based RAM, 63–64</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lossy techniques, 41</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>M</th>
<th>Maximum modulus pair (MMP), 17–18</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean RR-based CAN classifying architecture, 69</td>
</tr>
<tr>
<td></td>
<td>MIT-BIH ECG database, 47–49</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>N</th>
<th>Naive Bayes classifier, 79</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N-bit adders, 46</td>
</tr>
<tr>
<td></td>
<td>N-bit multiplier, 46</td>
</tr>
<tr>
<td></td>
<td>NFC, 12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>O</th>
<th>On-chip CAN classification, 60</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oxygen saturation monitoring, 9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P</th>
<th>Pan and Tompkins (PAT) algorithm, 3, 27, 40</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power gating, 24</td>
</tr>
<tr>
<td></td>
<td>Power optimization, 75–77</td>
</tr>
<tr>
<td></td>
<td>Principal component analysis (PCA), 15, 60</td>
</tr>
<tr>
<td></td>
<td>Proposed compressor architecture, 49–50</td>
</tr>
<tr>
<td></td>
<td>Proposed ECG compression architecture, 49–50, 53–55</td>
</tr>
<tr>
<td></td>
<td>Proposed QRS detection architecture, 41–42</td>
</tr>
<tr>
<td></td>
<td>algorithm formulation, 43–45</td>
</tr>
<tr>
<td></td>
<td>computational complexity, 52–53</td>
</tr>
<tr>
<td></td>
<td>false-positive detection, 50</td>
</tr>
<tr>
<td></td>
<td>MIT-BIH record, 50, 52</td>
</tr>
<tr>
<td></td>
<td>optimization parameters, 48</td>
</tr>
<tr>
<td></td>
<td>proposed ACLT architecture, 45–46</td>
</tr>
<tr>
<td></td>
<td>QRS peak detection, 46–48</td>
</tr>
<tr>
<td></td>
<td>sensitivity and positive predictivity, 51–52</td>
</tr>
<tr>
<td></td>
<td>P-wave, 14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q</th>
<th>QRS complex, 14</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>QRS detection, 27, 40, 64, 70–71</td>
</tr>
<tr>
<td></td>
<td>QT variability index (QTVI), 21–22, 62</td>
</tr>
<tr>
<td></td>
<td>QTVI, see QT variability index</td>
</tr>
<tr>
<td></td>
<td>QTVI-based CAN detection, 68–69</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R</th>
<th>Real-time QRS detector and ECG compression architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Renyi entropy, 62</td>
</tr>
<tr>
<td></td>
<td>RFID technologies, 12</td>
</tr>
<tr>
<td></td>
<td>RMSSD-based CAN detection, 69–70</td>
</tr>
<tr>
<td></td>
<td>Root mean square value of standard difference (RMSSD), 69–70</td>
</tr>
<tr>
<td></td>
<td>R-peak detection module, 78</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S</th>
<th>SD-based CAN detection, 70</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Squaring-CLT (S-CLT), 44</td>
</tr>
<tr>
<td></td>
<td>SRAM-based memory, 63–64</td>
</tr>
<tr>
<td></td>
<td>Strong support vector machine classifier, 21</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>T</th>
<th>Thermal energy harvesters, 27</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time domain morphology, 16</td>
</tr>
</tbody>
</table>
Time domain thresholding, 40
Tone and entropy (T-E) technique, 61–62
T-wave, 14

Ultra-low power CAN detection, 6
Ultra-low power ECG processor
circuit design techniques, 3
ECG node, 2
integrated biomedical processing platform, 4–5
minimize power consumption and energy dissipation, 3
PAT algorithm, 3
P-wave, 3
QRS complex, 3
total power consumption, 3–4
T-wave, 3
Ultra-low power QRS detection architecture, 5
Ultra-low power sensors, 9

Ultra-wideband (UWB), 12
U-wave, 14

VA prediction architecture, 6
Ventricular arrhythmia (VA), 4
Voltage scaling, 24
VTVF classifier architecture
ASIC design, 81–82
classification stage, 79
ECG pre-processing, 78
feature extraction stage, 78–79
secure VA prediction architecture, 80

Wavelet transform (WT), 16
Weak linear classifier, 21
Wearable technology, 11
Wireless data transmission, 40