数字滤波器

心电波形数据

本文中使用到的心电波形数据如下所示。

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1 /*
                 2 * 心电波形数据
                 3 * 采样率 2kHz
                 4 * 脉率值 60BPM
                 5 * 单位 mV
               7 const double g_arrEcgWave[4000] =
               8 {
                 9 - 0.05, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.0
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22 -0.06, -0.05, -0.06, -0.06, -0.06, -0.06, -0.05, -0.06, -0.06, -0.06, -0.05, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.0
                                                        0.05, -0.06, -0.05, -0.05, -0.05,
```

```
23 -0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.
```

- 24 -0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.05,-0.05,-0.06,-0.
- 25 -0.05,-0.05,-0.05,-0.05,-0.06,-0.05,-0.05,-0.05,-0.05,-0.05,-0.06,-0.
- 26 -0.06,-0.05,-0.05,-0.05,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.05,-0.05,-0.06,-0.06,-0.06,-0.06,-0.05,-0.05,-0.06,-0.
- 27 -0.06,-0.05,-0.05,-0.06,-0.05,-0.05,-0.05,-0.06,-0.06,-0.06,-0.05,-0.
- 28 -0.06,-0.06,-0.06,-0.06,-0.05,-0.05,-0.05,-0.06,-0.
- 29 -0.06,-0.06,-0.06,-0.05,-0.06,-0.05,-0.
- 30 -0.05,-0.05,-0.05,-0.05,-0.06,-0.05,-0.05,-0.05,-0.05,-0.06,-0.05,-0.06,-0.
- 31 -0.06, -0.06, -0.05, -0.0
- 32 -0.05,-0.
- 33 -0.06,-0.06,-0.06,-0.06,-0.05,-0.05,-0.05,-0.05,-0.05,-0.06,-0.05,-0.
- 34 -0.05,-0.06,-0.06,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.06,-0.06,-0.06,-0.05,0.05,-0.05,-0.05,-0.05,-0.05,
- 35 -0.05,-0.05,-0.06,-0.05,-0.06,-0.05,-0.05,-0.05,-0.06,-0.06,-0.05,-0.05,-0.06,-0.05,-0.
- 36 -0.05,-0.
- 37 -0.05, -0.05, -0.06, -0.06, -0.05, -0.0
- 38 -0.05,-0.06,-0.06,-0.05,-0.
- 39 -0.05,-0.05,-0.05,-0.06,-0.05,-0.
- 40 -0.05,-0.
- 41 -0.05,-0.
- 42 -0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.06,-0.06,-0.05,-0.
- 43 -0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.06,-0.
- 44 -0.05,-0.05,-0.05,-0.05,-0.06,-0.06,-0.05,-0.05,-0.06,-0.06,-0.06,-0.05,-0.
- 45 -0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.06,-0.06,-0.06,-0.06,-0.06,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,

- 46 -0.05,-0.06,-0.06,-0.05,-0.05,-0.05,-0.05,-0.05,-0.04,-0.04,-0.04,-0.04,-0.04,-0.03,-0.03,-0.02,-0.02,-0.03,

- $51 \quad 0.02, 0.02, 0.02, 0.02, 0.02, 0.02, 0.01, 0.02, 0.02, 0.02, 0.02, 0.01,$
- $52 \quad 0, -0.01, -0.01, -0.01, -0.01, -0.01, -0.02, -0.02, -0.02, -0.02, -0.03, -0.03, -0.03, -0.02, -0.03, -0.03, -0.03, -0.04,$
- 53 -0.04,-0.04,-0.04,-0.04,-0.05,-0.
- 54 -0.05,-0.06,-0.06,-0.05,-0.
- 55 -0.05,-0.
- 56 -0.06,-0.06,-0.05,-0.
- 57 -0.05, -0.0
- 58 -0.05,-0.06,-0.05,-0.05,-0.05,-0.06,-0.06,-0.06,-0.05,-0.
- 59 -0.06,-0.06,-0.05,-0.
- 60 -0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.06,-0.05,-0.
- 61 -0.05, -0.0
- 62 -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.06, -0.05, -0.0
- 63 -0.08, -0.08, -0.09, -0.1, -0.1, -0.1, -0.11, -0.12, -0.12, -0.12, -0.12, -0.14, -0.14, -0.14, -0.14, -0.15, -0.16, -0.17,
- $64 -0.19, -0.19, -0.19, -0.17, -0.13, -0.12, -0.12, -0.09, -0.05, -0.05, -0.05, -0.04, 0, 0.02, \\ 0.02, 0.03, 0.08, 0.09, 0.09, 0.11, 0.15,$
- 65 0.16,0.16,0.19,0.23,0.23,0.23,0.26,0.3,0.3,0.3,0.31,0.35,0.37,0.37,0.39,0.43,0. 44,0.44,0.45,0.49,0.51,0.51,0.53,
- 66 0.57,0.58,0.58,0.61,0.64,0.64,0.65,0.64,0.64,0.64,0.65,0.65,0.65,0.65,0.65,0.63,0.58,0.57,0.56,0.53,0.49,0.48,0.49,
- 67 0.47,0.42,0.4,0.4,0.38,0.34,0.32,0.32,0.3,0.26,0.24,0.24,0.22,0.17,0.16,0.15,0. 12,0.08,0.07,0.07,0.04,0,-0.01,-0.01,
- 68 -0.02,-0.07,-0.09,-0.09,-0.11,-0.16,-0.17,-0.17,-0.18,-0.24,-0.25,-0.25,-0.28,0.33,-0.33,-0.32,-0.29,-0.28,

- 69 -0.29, -0.28, -0.25, -0.23, -0.24, -0.23, -0.2, -0.2, -0.19, -0.18, -0.16, -0.15, -0.14, -0.13, -0.1, -0.1, -0.08, -0.05, -0.06,
- 70 -0.05, -0.05, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.05, -0.06, -0.06, -0.06, -0.05, -0.06, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.06, -0.0
- 71 -0.05, -0.05, -0.06, -0.05, -0.0
- 72 -0.05,-0.
- 73 -0.05, -0.05, -0.05, -0.04, -0.0
- 74 -0.04, -0.0
- 75 -0.04, -0.04, -0.04, -0.04, -0.04, -0.03, -0.03, -0.04, -0.04, -0.04, -0.03, -0.0
- 76 -0.03, -0.03, -0.03, -0.02, -0.02, -0.02, -0.03, -0.03, -0.03, -0.02, -0.02, -0.02, -0.03, -0.02, -0.0
- 77 -0.02, -0.02, -0.02, -0.02, -0.02, -0.02, -0.02, -0.02, -0.02, -0.01, -0.01, -0.02, -0.02, -0.02, -0.02, -0.01, -0.01, -0.02, -0.02, -0.01, -0.02, -0.0
- $78 \quad -0.02, -0.01, -0.01, -0.01, -0.01, -0.01, -0.01, -0.01, 0, -0.01,$
- 79 0.01, 0

- 89 0.16, 0.16, 0.16, 0.16, 0.16, 0.16, 0.17, 0.17, 0.17, 0.17, 0.16, 0.16, 0.16, 0.16, 0.16, 0.16, 0.16, 0.15, 0.1
- 90 0.15, 0.15, 0.15, 0.15, 0.14, 0.14, 0.14, 0.14, 0.13, 0.14, 0.13, 0.13, 0.13, 0.13, 0.13, 0.13, 0.13, 0.13, 0.12, 0.1

```
92 0.1,0.1,0.1,0.1,0.09,0.1,0.09,0.08,0.08,0.08,0.08,0.07,0.07,0.06,0.06,0.06,
0.05,0.05,0.05,0.04,0.04,0.04,
```

- 93 0.03,0.03,0.03,0.03,0.02,0.01,0.01,0.01,0.01,0,0,0,0,0,-0.01,-0.02,-0
- 94 -0.03,-0.03,-0.03,-0.03,-0.03,-0.04,-0.
- 95 -0.05,-0.05,-0.05,-0.06,-0.05,-0.05,-0.05,-0.06,-0.06,-0.06,-0.06,-0.05,-0.05,-0.05,-0.06,-0.
- 96 -0.06,-0.
- 97 -0.06,-0.05,-0.06,-0.06,-0.05,-0.05,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.06,-0.05,-0.05,-0.05,-0.05,-0.06,-0.
- 98 -0.06,-0.06,-0.05,-0.06,-0.06,-0.05,-0.05,-0.05,-0.06,-0.05,-0.06,-0.
- 99 -0.06,-0.06,-0.06,-0.06,-0.06,-0.05,-0.06,-0.
- $100 \quad -0.06, -0.05, -0.05, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.05, -0.06, -$
- $101 \quad -0.05, -0.05, -0.05, -0.06, -0.06, -0.06, -0.05, -0.05, -0.05, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.05, -$
- 102 -0.05,-0.05,-0.05,-0.06,-0
- 103 -0.06, -0.06, -0.05, -0.05, -0.06, -0.05, -0.
- 104 -0.05,-0.05,-0.05,-0.05,-0.06,-0.06,-0.05,-0.06,-0
- 105 -0.06, -0.06, -0.06, -0.06, -0.05, -0.06, -0.06, -0.05, -0.05, -0.05, -0.05, -0.05, -0.06, -0.
- 106 -0.05,-0.06,-0.05,-0.05,-0.05,-0.06,-0.05,-0.05,-0.06,-0
- 107 -0.06, -0.06, -0.06, -0.06, -0.06, -0.05, -0.05, -0.05, -0.06, -0.05, -0.05, -0.05, -0.06, -0.
- $108 \quad -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.06, -$
- 109 -0.06,-0.06,-0.05,-0.05,-0.06,-0.06,-0.06,-0.06,-0.06,-0.05,-0.06,-0
- $110 \quad -0.06, -0.06, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.06, -0.06, -0.06, -0.06, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.06, -$
- $111 \quad -0.05, -0.05, -0.05, -0.05, -0.06, -0.06, -0.05, -0.06, -$
- $112 \quad -0.05, -0.05, -0.05, -0.05, -0.06, -0.05, -0.05, -0.05, -0.06, -$
- $113 \quad -0.06, -0.06, -0.05, -0.06, -0.05, -0.05, -0.06, -0.06, -0.05, -0.05, -0.05, -0.05, -0.06, -$
- $114 \quad -0.06, -0.05, -0.06, -0.06, -0.05, -$

```
115 \quad -0.05, -0.05, -0.06, -0.06, -0.06, -0.06, -0.06, -0.05, -0.05, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -
```

- $116 \quad -0.06, -0.05, -0.06, -0.05, -0.05, -0.06, -0.06, -0.05, -$
- 117 -0.05, -0.05, -0.05, -0.06, -0.05, -0.05, -0.06, -0.05, -0.06, -0.05, -0.06, -0.05, -0.06, -0.06, -0.06, -0.05, -0.
- $118 \quad -0.05, -0.05, -0.06, -0.06, -0.05, -0.05, -0.05, -0.06, -0.06, -0.06, -0.06, -0.05, -$
- $119 \quad -0.05, -0.05, -0.05, -0.06, -0.06, -0.06, -0.05, -0.05, -0.05, -0.06, -0.05, -0.05, -0.05, -0.05, -0.05, -0.06, -0.06, -$
- 120 -0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.06,-0.05,-0
- $121 \quad -0.05, -$
- $122 \quad -0.05, -$
- 123 -0.05,-0
- 124 -0.05,-0.05,-0.05,-0.05,-0.05,-0.06,-0.06,-0.06,-0.05,-0
- 125 -0.05,-0
- 126 -0.05,-0
- 127 -0.05,-0
- 128 -0.05,-0.06,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.06,-0.06,-0.06,-0.05,-0
- 129 -0.05,-0
- $130 \quad -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.06, -0.06, -0.06, -0.06, -0.06, -0.06, -0.05, -$
- $131 \quad -0.05, -$
- 132 -0.05,-0
- 133 -0.05,-0
- 134 -0.05,-0.05,-0.06,-0.05,-0
- 135 -0.05,-0
- 136 -0.05,-0
- 137 -0.05, -0.

```
138 -0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0
```

- 139 -0.05,-0
- 140 -0.05,-0
- $141 \quad -0.06, -0.05, -$
- $142 \quad -0.05, -$
- 143 -0.05,-0
- 144 -0.05,-0
- $145 \quad -0.05, -$
- $146 \quad -0.04, -0.04, -0.04, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.04, -0.04, -0.04, -0.04, -0.04, -0.03, -0.03, -0.03, -0.03$
- 147 -0.03, -0.03, -0.03, -0.03, -0.02, -0.03, -0.02, -0.02, -0.02, -0.02, -0.02, -0.02, -0.02, -0.01, -0.01, -0.01, -0.01, 0.01, 0.01, 0.01, 0.01, -0.01,

- 152 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.00, 0, 0, 0, 0, -0.01
- $153 \quad -0.02, -0.03, -0.03, -0.03, -0.03, -0.03, -0.03, -0.04, -0.04, -0.04, -0.04, -0.05, -$
- 154 -0.05,-0
- 155 -0.05,-0.05,-0.05,-0.05,-0.04,-0.04,-0.04,-0.05,-0
- 156 -0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.06,-0.05,-0
- $157 \quad -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.04, -0.04, -0.05, -0.05, -0.05, -0.05, -0.04, -0.04, -0.05, -0.05, -0.05, -0.04, -0.04, -0.05, -0.05, -0.05, -0.04, -0.05, -0.05, -0.05, -0.04, -0.04, -0.04, -0.05, -$
- 158 -0.04,-0.05,-0.05,-0.05,-0.05,-0.04,-0.05,-0.04,-0.05,-0
- 159 -0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.04,0.05,-0.05,-0.05,-0.05,-0.05,-0.05,
- 160 -0.05,-0

```
161 \quad -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -
```

- 162 -0.05,-0
- 163 -0.1, -0.1, -0.11, -0.12, -0.12, -0.12, -0.13, -0.14, -0.14, -0.14, -0.15, -0.16, -0.17, -0.17, -0.19, -0.19, -0.17, -0.13,
- 164 -0.12,-0.12,-0.11,-0.06,-0.04,-0.04,-0.03,0,0.02,0.02,0.03,0.06,0.09,0.1,0.11,0 .15,0.16,0.16,0.18,0.22,0.23,0.23,
- 165 0.24,0.28,0.3,0.31,0.35,0.37,0.37,0.38,0.42,0.44,0.44,0.46,0.5,0.51,0.51,0. 54,0.57,0.58,0.59,0.63,0.65,
- 166 0.65, 0.65, 0.65, 0.65, 0.65, 0.65, 0.65, 0.65, 0.65, 0.63, 0.58, 0.57, 0.57, 0.54, 0.5, 0.48, 0.49, 0.48, 0.44, 0.41, 0.4, 0.39, 0.35,
- 167 0.33, 0.32, 0.27, 0.24, 0.24, 0.22, 0.18, 0.16, 0.16, 0.14, 0.09, 0.08, 0.08, 0.07, 0.02, -0.01, 0, -0.02, -0.06, -0.09, -0.09,
- $168 \quad -0.1, -0.14, -0.17, -0.17, -0.19, -0.24, -0.25, -0.25, -0.28, -0.33, -0.33, -0.33, -0.32, -0.33, -0.29, -0.28, -0.28, -0.25, -0.24,$
- $169 \quad -0.24, -0.24, -0.21, -0.19, -0.19, -0.18, -0.15, -0.14, -0.14, -0.13, -0.1, -0.1, -0.09, -0.09, -0.06, -0.05, -0.$
- 170 -0.05, -0.
- 171 -0.05, -0.
- 172 -0.05, -0.05, -0.05, -0.05, -0.04, -0.05, -0.05, -0.05, -0.05, -0.04, -0.04, -0.04, -0.05, -0.05, -0.05, -0.05, -0.05, -0.05, -0.04, -0.
- $173 \quad -0.04, -$
- 174 0.04, -0.04, -0.04, -0.03, -0.03, -0.04, -0.04, -0.04, -0.03, -0.03, -0.03, -0.03, -0.03, -0.04, -0.04, -0.04, -0.03, -0.04, -0.03, -0.04, -0.03, -0.04, -0.03, -0.04, -0.03, -0.04, -0.04, -0.03, -0.04, -0
- 175 -0.03, -0.
- $176 \quad -0.03, -0.02, -0.03, -0.02, -$
- $177 \quad -0.02, -0.02, -0.02, -0.01, -$
- $178 \quad -0.01, 0, 0, 0, -0.01, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.01, 0.01, 0, 0, 0, 0.01,$

- 183 0.06, 0.06, 0.06, 0.06, 0.06, 0.06, 0.06, 0.06, 0.06, 0.06, 0.06, 0.06, 0.07, 0.

- 188 0.16, 0.16, 0.16, 0.15, 0.15, 0.16, 0.16, 0.16, 0.16, 0.16, 0.16, 0.16, 0.16, 0.16, 0.17, 0.17, 0.17, 0.17, 0.16, 0.
- 189 0.17, 0.17, 0.17, 0.17, 0.17, 0.17, 0.17, 0.16, 0.16, 0.16, 0.16, 0.16, 0.15, 0.15, 0.15, 0.15, 0.15, 0.15, 0.14,

- 193 0.02, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, -0.01, -0.02, -0.0
- 194 -0.03,-0.03,-0.03,-0.03,-0.03,-0.03,-0.04,-0.04,-0.04,-0.05,-0.05,-0.04,-0.04,-0.04,-0.05,-0.05,-0.06,
- $195 \quad -0.06, -0.05, -0.05, -0.05, -0.05, -0.05, -0.06, -0.06, -0.06, -0.05, -$
- 196 -0.05,-0.05,-0.05,-0.05,-0.06,-0.05,-0
- 197 -0.05,-0.05,-0.05,-0.06,-0.06,-0.05,-0
- 198 -0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.06,-0.06,-0.05,-0
- 199 -0.05,-0.06,-0.05,-0.05,-0.06,-0.05,-0
- 200 -0.05,-0.05,-0.05,-0.05,-0.06,-0.05,-0
- 201 -0.05,-0.06,-0.05,-0.05,-0.05,-0.06,-0.06,-0.05,-0
- 202 -0.05,-0
- 203 -0.06,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.06,-0.05,-0.06,-0.05,-0
- 204 -0.05,-0.05,-0.05,-0.05,-0.06,-0.05,-0
- 205 -0.06,-0.06,-0.05,-0
- 206 -0.05,-0

```
207 -0.05,-0.05,-0.05,-0.05,-0.06,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0.05,-0
```

需要包含的头文件

```
1 #include <stdio.h>
2 #include <stdlib.h>
3 #include <malloc.h>
4 #include <math.h>
```

随机数生成

测试过程中需要用随机数生成噪声,生成随机数代码如下所示。

```
********
2 * 函数名称: Uniform
3 * 函数功能: 生成均匀分布的随机数
4 * 输入参数: a: 区间下限
           b: 区间上限
5 *
           seed: 随机数种子
6 *
7 * 输出参数: void
8 * 返回值: 随机数
9 * 创建日期: 2023年08月10日
10 * 注 意:
  *********
12 double Uniform(double a, double b, long int* seed)
13 {
14 double t;
  *seed = 2045 * (*seed) + 1;
15
  *seed = *seed - (*seed / 1048576) * 1048576;
16
t = (*seed) / 1048576.0;
  t = a + (b - a) * t;
18
19
   return t;
```

```
20 }
  *********
22 * 函数名称: Gauss
23 * 函数功能: 生成正态分布的随机数
24 * 输入参数: mean: 正态分布的均值 μ
25 *
          sigma: 正态分布的均方差o
26 *
          seed: 随机数种子
27 * 输出参数: void
28 * 返回值: 随机数
29 * 创建日期: 2023年08月10日
30 * 注 意:
**********
32 double Gauss(double mean, double sigma, long int* seed)
33 {
34 int i;
35 double x, y;
  for (x = 0, i = 0; i < 12; i++)
36
37
   x += Uniform(0.0, 1.0, seed);
38
   }
39
40 \quad x = x - 6.0;
41 y = mean + x * sigma;
42 return y;
43 }
```

维纳(Wiener)数字滤波

维纳(Wiener)数字滤波器实现代码如下所示。

```
1 /***************************
 ********
2 * 函数名称: Levin
3 * 函数功能: 求解一般托布利兹方程组的莱文森算法
4 * 输入参数: t: 双精度实型一维数组,长度为 n。存放对称托布利兹矩阵的元素 t0,t1,...,tn-
 10
         b:双精度实型一维数组,长度为 n。存放方程组右端的常数常量。
5 *
         n: 整形变量。方程组的阶数。
6 *
         x: 双精度实型一维数组,长度为 n。存放方程组的解。
7 *
8 * 输出参数: void
9 * 返回值: 本函数的返回值若小于 0,则说明方程是病态的。
10 * 创建日期: 2023年09月20日
11 * 注 意:
```

```
*********
13 int Levin(double* t, double* b, int n, double* x)
14 {
     int i, j, k;
15
16
     double a, beta, q, c, h, *y, *s;
     s = malloc(n * sizeof(double));
17
18
     y = malloc(n * sizeof(double));
19
     a = t[0];
     if ((fabs(a) + 1.0) == 1.0)
20
21
22
       free(s);
       free(y);
23
24
       return (-1);
25
     }
26
     y[0] = 1.0;
     x[0] = b[0] / a;
27
28
     for (k = 1; k < n; k++)
29
     {
30
       beta = 0.0;
31
       q = 0.0;
       for (j = 0; j < k; j++)
32
33
34
        beta += y[j] * t[j + 1];
35
         q += x[j] * t[k - j];
       }
36
       if ((fabs(a) + 1.0) == 1.0)
37
38
39
         free(s);
40
         free(y);
41
         return (-1);
       }
42
43
       c = -beta / a;
44
       s[0] = c * y[k - 1];
45
       y[k] = y[k - 1];
       if (k != 1)
46
47
       {
         for (i = 1; i < k; i++)
48
49
           s[i] = y[i - 1] + c * y[k - i - 1];
50
         }
51
52
53
       s[k] = y[k - 1];
       a += c * beta;
54
       if ((fabs(a) + 1.0) == 1.0)
55
56
       {
57
         free(s);
```

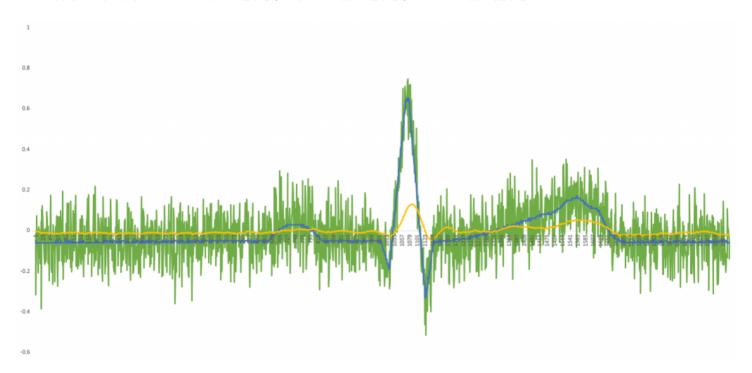
```
58
      free(y);
59
      return (-1);
      }
60
      h = (b[k] - q) / a;
61
      for (i = 0; i < k; i++)
62
63
      {
      x[i] += h * s[i];
64
      y[i] = s[i];
65
66
      }
     x[k] = h * y[k];
67
68
    free(s);
69
   free(y);
70
   return (1);
71
72 }
********
74 * 函数名称: Wiener
75 * 函数功能: 维纳数字滤波
76 * 输入参数: rxx: 双精度实型一维数组,长度为 (p+1) 。信号 x(n) 的自相关函数 rxx(i) 。
            rdx: 双精度实型一维数组,长度为(p+1)。信号 d(n) 与 x(n) 的互相关函数
77 ×
  rdx(i)_{o}
            p : 整型变量。维纳滤波器的阶数。
78 *
            h : 双精度实型一维数组,长度为 (p+1) 。维纳滤波器的系数。
79 *
            e : 双精度实型变量。维纳滤波器的最小均方误差。
80 *
            x : 双精度实型一维数组,长度为 n。存放输入信号 x(i)。
81 *
            y : 双精度实型一维数组,长度为 n。存放输出信号 y(i)。
82 *
            n :整形变量。输入信号的长度。
83 *
84 * 输出参数: void
85 * 返回值: void
86 * 创建日期: 2023年09月21日
87 * 注 意:
88 *********************************
   *********
89 void Wiener(double* rxx, double* rdx, int p, double* h, double* e, double* x,
   double* y, int n)
90 {
    int i, k;
91
    double sum;
92
    Levin(rxx, rdx, p + 1, h);
93
94
    sum = 0.0;
    for (i = 0; i <= p; i++)
95
96
97
    sum += rdx[i] * h[i];
98
    }
99
    *e = rdx[0] - sum;
    for (k = 0; k < n; k++)
100
```

```
101
        y[k] = 0.0;
102
        for (i = 0; i <= p; i++)
103
104
         if ((k - i) >= 0)
105
106
         {
           y[k] += h[i] * x[k - i];
107
108
109
       }
110
111 }
```

维纳(Wiener)滤波器的使用如下所示。其中心电波形数据为模拟器标准数据,脉率值为 60BPM,采样率为 2kHz,在文章的末尾给出。

```
1 int main(void)
2 {
    extern const double g_arrEcgWave[4000];
3
     int i, k, n, p;
 4
    long seed;
5
     double e;
 6
7
     static double rxx[4000], rdx[4000];
8
     static double h[4000], x[4000], y[4000], s[4000];
    FILE* fp;
9
10
    //获取原始数据
11 n = 2000;
    for (i = 0; i < n; i++)
12
13
    s[i] = g_arrEcgWave[i];
14
15
     }
    //添加白噪声
16
17
    seed = 157l;
     for (i = 0; i < n; i++)
18
19
20
     x[i] = s[i] + 0.1 * Gauss(0.0, 1.0, &seed);
     }
21
     //生成互相关函数
22
     p = 2000;
23
     for (k = 0; k \le p; k++)
24
25
    {
      rdx[k] = 0.0;
26
      for (i = 0; i < (n - k); i++)
27
28
       {
        rdx[k] += s[i] * s[i + k];
29
30
       }
```

```
rdx[k] = rdx[k] / n;
31
     }
32
     //生成自相关函数
33
     rxx[0] = rdx[0] + 1.0;
34
    for (i = 1; i <= p; i++)
35
     {
36
37
     rxx[i] = rdx[i];
     }
38
     //滤波
39
     Wiener(rxx, rdx, p, h, &e, x, y, n);
40
     printf("The Minimum MSE Error = %lf\n", e);
41
     //输出波形数据,按照原始信号、参考信号、滤波后信号顺序
42
     fp = fopen("wieners.csv", "w");
43
    for (i = 0; i < n; i++)
44
45
    fprintf(fp, "%d,%lf,%lf,%lf\n", i, x[i], s[i], y[i]);
46
47
     fclose(fp);
48
49
     return 0;
50 }
```



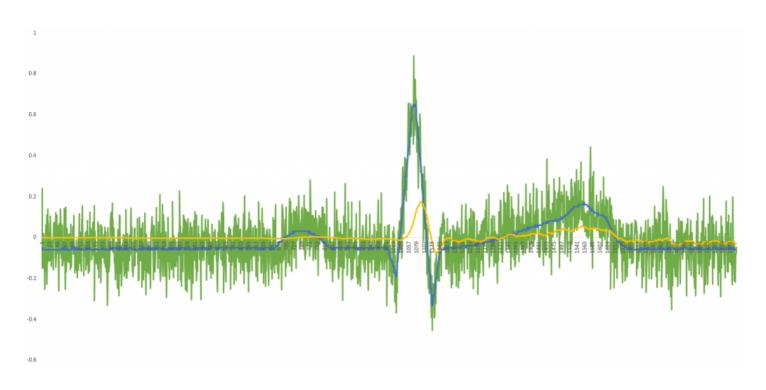
最小均方(LMS)自适应数字滤波

实现代码如下所示。

```
2 * 函数名称: LMS
3 * 函数功能: 最小均方(LMS)自适应数字滤波
4 * 输入参数: x: 双精度实型一维数组,长度为 n。输入信号。
            d: 双精度实型一维数组,长度为 n。理想输出信号。
5 *
            v: 双精度实型一维数组,长度为 n。实际输出信号。
6 *
            n : 整型变量。输入信号的长度。
7
            w: 双精度实型一维数组,长度为 m。自适应滤波器的加权系数。
            m : 整型变量。自适应滤波器的长度(阶数-1)。
9 *
            mu:双精度实型变量。收敛因子。
10 *
11 * 输出参数: void
12 * 返回值: void
13 * 创建日期: 2023年09月22日
14 * 注 意:
15 ****************************
  **********
16 void LMS(double* x, double* d, double* y, int n, double* w, int m, double mu)
17 {
18
    int i, k;
    double e;
19
    for (i = 0; i < m; i++)
20
21
    {
22
    w[i] = 0.0;
23
24
    for (k = 0; k < m; k++)
25
    {
26
     y[k] = 0.0;
27
     for (i = 0; i <= k; i++)
28
      y[k] += x[k - i] * w[i];
29
     }
30
31
     e = d[k] - y[k];
     for (i = 0; i <= k; i++)
32
33
      w[i] += 2.0 * mu * e * x[k - i];
34
35
     }
36
    }
37
    for (k = m; k < n; k++)
38
    {
     y[k] = 0.0;
39
     for (i = 0; i < m; i++)
40
41
      {
      y[k] += x[k - i] * w[i];
42
43
      }
     e = d[k] - y[k];
44
45
     for (i = 0; i < m; i++)
46
47
       w[i] += 2.0 * mu * e * x[k - i];
```

```
48 }
49 }
50 }
```

```
1 int main(void)
2 {
3
    extern const double g_arrEcgWave[4000];
    int i, m, n;
    long seed;
5
    double mu;
6
    static double d[4000], x[4000], y[4000], w[4000];
7
8
    FILE* fp;
9
    //获取理想输出信号
10
    n = 2000;
    for (i = 0; i < n; i++)
11
12
13
    d[i] = g_arrEcgWave[i];
14
    //获取输入数据,加噪声
15
16
    seed = 13579l;
    for (i = 0; i < n; i++)
17
18
19
    x[i] = g_arrEcgWave[i] + 0.1 * Gauss(0.0, 1.0, &seed);
20
    }
    //LMS 滤波
21
m = 50;
    mu = 0.0005;
23
    LMS(x, d, y, n, w, m, mu);
24
    //输出波形数据,按照原始信号、参考信号、滤波后信号顺序
25
    fp = fopen("lms.csv", "w");
26
    for (i = 0; i < n; i++)
27
28
    {
     fprintf(fp, "%d,%lf,%lf,%lf\n", i, x[i], d[i], y[i]);
29
30
    fclose(fp);
31
32
  return 0;
33 }
```



归一化(LMS)自适应数字滤波

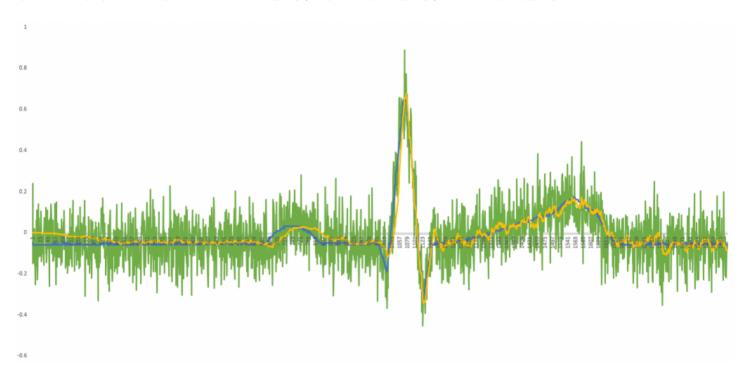
实现代码如下所示。

```
*********
2 * 函数名称: NLMS
3 * 函数功能: 归一化 (LMS) 自适应数字滤波
               : 双精度实型一维数组,长度为 n。开始时存放输入信号,最后存放实际输出信
4 * 输入参数: x
  号。
                : 双精度实型一维数组,长度为 n。理想输出信号。
                : 整型变量。输入信号的长度。
                : 双精度实型一维数组,长度为 m。自适应滤波器的加权系数。
                :整型变量。自适应滤波器的长度(阶数-1)。
8
            m
                :双精度实型变量。学习因子, 0 < mu < 1。
9
            mu
            sigma2: 双精度实型变量。输入信号的功率估值 σ^2。
10 *
                :双精度实型变量。遗忘因子,0 <= a <= 1。
11 *
            а
12 *
                : 双精度实型一维数组, 长度为 m。在分块处理时, 用于保存输入信号的过去
            рх
  值。
13 * 输出参数:
           void
14 * 返回值:
           void
15 * 创建日期:
           2023年09月23日
16 * 注
       意:
  *********
18 void NLMS(double* x, double* d, int n, double* w, int m, double mu, double
  sigma2, double a, double* px)
19 {
20
   int i, k;
   double e, tmp;
21
```

```
22
     for (k = 0; k < n; k++)
23
     {
24
       px[0] = x[k];
       x[k] = 0.0;
25
       for (i = 0; i < m; i++)
26
27
       {
28
         x[k] += px[i] * w[i];
29
30
       e = d[k] - x[k];
31
       sigma2 = a * px[0] * px[0] + (1.0 - a) * sigma2;
32
       tmp = 2 * mu / (m * sigma2);
       for (i = 0; i < m; i++)
33
34
35
        w[i] += tmp * e * px[i];
36
       for (i = (m - 1); i >= 1; i--)
37
       {
38
39
        px[i] = px[i - 1];
40
       }
41 }
42 }
```

```
1 int main(void)
2 {
   extern const double g_arrEcgWave[4000];
3
4
    int i, m, n;
    double a, mu, sigma2;
5
6
     long seed;
7
     static double d[4000], x[4000], y[4000], w[4000], px[4000];
8
     FILE* fp;
    //获取理想输出信号
9
    for (i = 0; i < 2000; i++)
10
11
    d[i] = g_arrEcgWave[i];
12
13
    //获取输入数据,加噪声
14
15
    seed = 13579l;
    n = 2000;
16
    for (i = 0; i < n; i++)
17
18
19
      x[i] = g_arrEcgWave[i] + 0.1 * Gauss(0.0, 1.0, &seed);
20
      y[i] = x[i];
```

```
21
     }
    //LMS 滤波
22
    m = 51;
23
24
    mu = 0.2;
    sigma2 = 0.2;
25
     a = 0;
26
27
    for (i = 0; i < m; i++)\{w[i] = 0.0;\}
    for (i = 0; i < m; i++){px[i] = 0.0;}
28
    NLMS(y, d, n, w, m, mu, sigma2, a, px);
29
    //输出波形数据,按照原始信号、参考信号、滤波后信号顺序
30
    fp = fopen("nlms.csv", "w");
31
    for (i = 0; i < n; i++)
32
33
     fprintf(fp, "%d,%10.7lf,%10.7lf,%10.7lf\n", i, x[i], d[i], y[i]);
34
35
36
   return 0;
37 }
```



递推最小二乘(RLS)自适应数字滤波

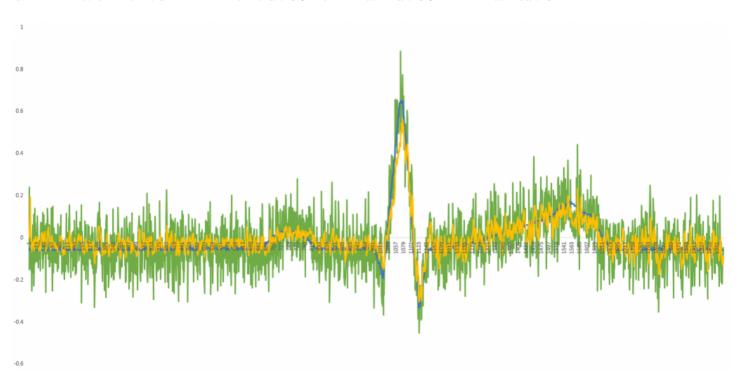
实验代码如下所示。

```
d: 双精度实型一维数组,长度为 n。理想输出信号。
5 *
              n: 整型变量。输入信号的长度。
6
               w: 双精度实型一维数组,长度为 m。自适应滤波器的加权系数。
7 *
              m: 整型变量。自适应滤波器的长度(阶数-1)。
8
              r: 双精度实型变量。遗忘因子, 0 < r <= 1。
9 *
10 * 输出参数:
             void
11 * 返回值: void
12 * 创建日期:
             2023年09月23日
13 * 注 意:
   *********
15 void RLS(double* x, double* d, int n, double* w, int m, double r)
16 {
17
    int i, j, k;
    double a, s, *g, *u, *px, *p;
18
19
    g = malloc(m * sizeof(double));
20
    u = malloc(m * sizeof(double));
21
    px = malloc(m * sizeof(double));
22
    p = malloc(m * m * sizeof(double));
    for (i = 0; i < m; i++)
23
24
    {
      for (j = 0; j < m; j++)
25
26
27
        p[i * m + j] = 0.0;
28
      }
29
30
    for (i = 0; i < m; i++)
31
32
     p[i * m + i] = 1.0e+8;
33
    for (i = 0; i < m; i++)
34
35
     px[i] = 0.0;
36
37
    }
38
    for (k = 0; k < n; k++)
39
40
      px[0] = x[k];
      for (j = 0; j < m; j++)
41
42
        u[j] = 0.0;
43
        for (i = 0; i < m; i++)
44
45
          u[j] = u[j] + (1 / r) * p[j * m + i] * px[i];
46
47
48
      }
49
      s = 1.0;
      for (i = 0; i < m; i++)
50
```

```
51
         s = s + u[i] * px[i];
52
       }
53
54
       for (i = 0; i < m; i++)
55
         g[i] = u[i] / s;
56
57
       }
58
       x[k] = 0.0;
59
       for (i = 0; i < m; i++)
60
         x[k] = x[k] + w[i] * px[i];
61
62
       a = d[k] - x[k];
63
       for (i = 0; i < m; i++)
64
65
66
         w[i] = w[i] + g[i] * a;
67
       }
68
       for (j = 0; j < m; j++)
69
         for (i = 0; i < m; i++)
70
71
         {
           p[j * m + i] = (1 / r) * p[j * m + i] - g[j] * u[i];
72
73
         }
74
       }
       for (i = (m - 1); i >= 1; i--)
75
76
       {
77
         px[i] = px[i - 1];
78
79
80
     free(g);
     free(u);
81
     free(px);
82
83
   free(p);
84 }
```

```
1 int main(void)
2 {
3    extern const double g_arrEcgWave[4000];
4    int i, m, n;
5    long seed;
6    static double r, w[4000], d[4000], x[4000], y[4000];
7    FILE* fp;
```

```
//获取理想输出信号
    for (i = 0; i < 2000; i++)
9
10
    d[i] = g_arrEcgWave[i];
11
12
    //获取输入数据,加噪声
13
14
    seed = 13579l;
    n = 2000;
15
    for (i = 0; i < n; i++)
16
17
     x[i] = g_arrEcgWave[i] + 0.1 * Gauss(0.0, 1.0, &seed);
18
19
     y[i] = x[i];
    }
20
21
    // RLS 滤波
22
    m = 4;
23
   r = 1.0;
    for (i = 0; i < m; i++){ w[i] = 0.0;}
24
25
    RLS(y, d, n, w, m, r);
    //输出波形数据,按照原始信号、参考信号、滤波后信号顺序
26
    fp = fopen("rls.csv", "w");
27
    for (i = 0; i < n; i++)
28
29
    fprintf(fp, "%d,%10.7lf,%10.7lf,%10.7lf\n", i, x[i], d[i], y[i]);
30
31
32
   return 0;
33 }
```



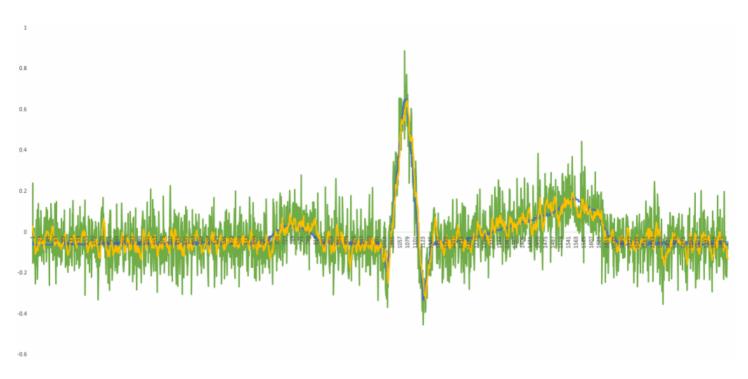
滑动平均滤波

实现代码如下。

```
********
2 * 函数名称: MovAverageFilter
3 * 函数功能: 滑动平均滤波
4 * 输入参数: filter: 双精度实型一维数组,长度为 oder。滤波缓冲区。
           order : 整型变量。滤波阶数。
           dat :双精度实型变量。新的采样数据
7 * 输出参数: void
8 * 返回值:滤波值
9 * 创建日期: 2023年09月20日
10 * 注 意:
11 ********************************
  *********
12 double MovAverageFilter(double* filter, int order, double dat)
13 {
14 int i;
15 double sum;
16 for (i = 0; i < order - 1; i++)
17
   filter[i] = filter[i + 1];
18
19
20
   filter[order - 1] = dat;
21
  sum = 0;
22
  for (i = 0; i < order; i++)
23
24
  sum = sum + filter[i];
25
26  sum = sum / order;
27 return sum;
28 }
```

```
1 int main(void)
2 {
3   extern const double g_arrEcgWave[4000];
4   #define FILTER_ORDER 8
5   static double s_arrFilter[FILTER_ORDER] = {0};
```

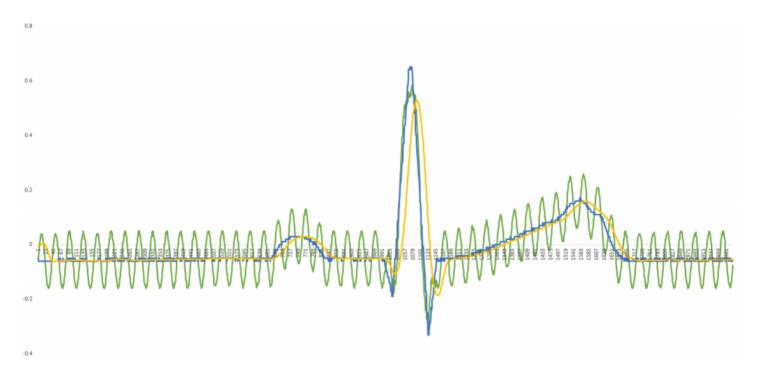
```
int i, n;
7
    long seed;
    static double d[4000], x[4000], y[4000];
8
9
    FILE* fp;
    //获取理想输出信号
10
11 n = 2000;
12
    for (i = 0; i < 2000; i++)
13
14
    d[i] = g_arrEcgWave[i];
15
    //获取输入数据,加噪声
16
17 seed = 13579l;
  for (i = 0; i < n; i++)
18
19
    x[i] = g_arrEcgWave[i] + 0.1 * Gauss(0.0, 1.0, &seed);
20
21
    }
    //滑动平均滤波
22
23
    for (i = 0; i < n; i++)
24
    y[i] = MovAverageFilter(s_arrFilter, FILTER_ORDER, x[i]);
25
26
    }
    //输出波形数据,按照原始信号、参考信号、滤波后信号顺序
27
28  fp = fopen("MovAverageFilter.csv", "w");
29 for (i = 0; i < n; i++)
30
    {
     fprintf(fp, "%d,%10.7lf,%10.7lf,%10.7lf\n", i, x[i], d[i], y[i]);
31
32
33
   return 0;
34 }
```



心电信号添加 50Hz 工频干扰,利用滑动平均滤波滤除工频干扰示例如下。2kHz 采样率下滤波阶数为 40,500Hz 采样率下滤波阶数为 10,其它采样率可以根据这个规律设置滤波阶数。

```
1 int main(void)
2 {
    extern const double g_arrEcgWave[4000];
     #define FILTER ORDER 40
4
     static double s arrFilter[FILTER ORDER] = { 0 };
5
     int i, n;
6
7
     long seed;
     static double d[4000], x[4000], y[4000];
8
     double pi, time;
9
10
     FILE* fp;
11
    //获取理想输出信号
12
     n = 2000;
    for (i = 0; i < 2000; i++)
13
14
     {
     d[i] = g_arrEcgWave[i];
15
16
     //获取输入数据,加 50Hz 工频干扰
17
18
     seed = 13579l;
     pi = 3.1415926535;
19
     time = 0;
20
21
     for (i = 0; i < n; i++)
22
       x[i] = g_arrEcgWave[i] + 0.1 * sin(time * 2 * pi / (1.0 / 50.0));
23
       time = time + 0.0005;
24
25
     }
     //滑动平均滤波
26
    for (i = 0; i < n; i++)
27
```

```
28
     y[i] = MovAverageFilter(s_arrFilter, FILTER_ORDER, x[i]);
29
    }
30
    //输出波形数据,按照原始信号、参考信号、滤波后信号顺序
31
    fp = fopen("MovAverageFilter.csv", "w");
32
    for (i = 0; i < n; i++)
33
34
    fprintf(fp, "%d,%10.7lf,%10.7lf,%10.7lf\n", i, x[i], d[i], y[i]);
35
36
37
   return 0;
38 }
```



中值滤波

实现代码如下。

```
11 * 注 意:
   *********
13 double MedianFilter(double* filter1, double* filter2, int order, double dat)
14 {
    int i, j;
15
     double swap;
16
     //将最新的数据保存到缓冲区 1
17
18
     for (i = 0; i < order - 1; i++)
19
     filter1[i] = filter1[i + 1];
20
21
     filter1[order - 1] = dat;
22
    //将数据拷贝到缓冲区 2
23
    for (i = 0; i < order; i++)
24
25
     filter2[i] = filter1[i];
26
27
     }
     //重新排序
28
     for (i = 0; i < order; i++)</pre>
29
30
      for (j = i + 1; j < order; j++)
31
32
33
        if (filter2[j] > filter2[i])
        {
34
          swap = filter2[j];
35
          filter2[j] = filter2[i];
36
          filter2[i] = swap;
37
38
        }
      }
39
40
    //返回中位值
41
42 return filter2[order / 2];
43 }
```

```
1 int main(void)
2 {
3    extern const double g_arrEcgWave[4000];
4    #define FILTER_ORDER 8
5    static double s_arrFilter1[FILTER_ORDER] = { 0 };
6    static double s_arrFilter2[FILTER_ORDER] = { 0 };
7    int i, n;
```

```
8
    long seed;
     static double d[4000], x[4000], y[4000];
9
    FILE* fp;
10
    //获取理想输出信号
11
    n = 2000;
12
    for (i = 0; i < 2000; i++)
13
14
    d[i] = g_arrEcgWave[i];
15
16
    //获取输入数据,加噪声
17
    seed = 13579l;
18
    for (i = 0; i < n; i++)
19
20
    x[i] = g_arrEcgWave[i] + 0.1 * Gauss(0.0, 1.0, &seed);
21
     }
22
    //滑动平均滤波
23
    for (i = 0; i < n; i++)
24
25
26
    y[i] = MedianFilter(s_arrFilter1, s_arrFilter2, FILTER_ORDER, x[i]);
27
    //输出波形数据,按照原始信号、参考信号、滤波后信号顺序
28
    fp = fopen("MedianFilter.csv", "w");
29
    for (i = 0; i < n; i++)
30
31
     fprintf(fp, "%d,%10.7lf,%10.7lf,%10.7lf\n", i, x[i], d[i], y[i]);
32
    }
33
34
   return 0;
35 }
```

